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NICKEL ORES FROM KEY WEST MINE, NEVADA.

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In March 1919 a suite of twelve specimens of ore stated to represent average nickel ore of the Key West Mine, in Southern Nevada, was transmitted to us by Dr. Charles L. Whittle, with the request that an examination be made to determine the minerals contained and their relations.

The Key West Mine, in Clark County, in Southern Nevada, was briefly described by Bancroft in 1909.[1] The district lies about twenty-four miles east southeast of Moapa on the Salt Lake and San Pedro railroad line. As described by Bancroft the deposits are contained in basic dikes of probably pre-Cambrian age intruded in gneisses of the same age. The strike of the dikes conforms in general with that of the gneisses and trends northeasterly. The Great Eastern dike is described as an enstatite-mica picrite, a variety of peridotite. The rock contains magnetite, pyrrhotite, and chalcopyrite; assays of the rock showed 0.26 per cent. nickel and a trace of platinum. The workings show much oxidation with large quantities of the oxides and sulphides of copper.

An analysis of the ore-bearing dike by Ledoux & Company runs as follows:

[1] Bancroft, Howland, "Platinum in Southeastern Nevada," Bull. 430, U. S. Geol. Survey, pp. 192–199, 1909.

ANALYSIS OF DIKE IN LOWER GREAT EASTERN ADIT.

Silica	24.88	Copper by electrolytic assay	2.01
Iron	19.35	Nickel	5.38
Alumina	4.21	Cobalt	.04
Lime	4.51	Platinum metals, 0.17 ounce.	
Magnesia	13.94	Gold, trace.	
Sulphur	18.02	Silver, trace.	

Another dike showed the composition of a hornblendite, a holocrystalline rock with 3 millimeter grain.

The Key West dike proved to be extremely decomposed and Bancroft does not determine its original character. The decomposed dike near the surface contained 0.1 ounces of platinum to the ton and 1.47 per cent. nickel, no gold or silver being present. One specimen of ore assayed 0.12 ounces of platinum to the ton and 5.6 per cent. nickel with no gold or silver, copper content not being determined. At the time of Bancroft's visit the workings of the Key West Mine amounted to 3,000 linear feet, the deepest shaft being 312 feet. Some trial shipments have been made.

Bancroft concludes that the basic dikes which are from 10 to 50 feet wide contain primary magnetite, pyrite, chalcopyrite, platinum, and pyrrhotite. No pyrrhotite was found in the Key West dike and Bancroft suggests that this mineral may have been transformed to pyrite by the action of infiltrating solutions. The deposits are considered to be of magmatic origin similar to the nickel deposits of Sudbury, Ontario. This closes the extracts from Bancroft's report.

The present paper does not deal with the content of the ore in platinum metals, but it may be stated that there is much more palladium than platinum. An analysis of the best ore by Professor E. E. Bugbee of the Institute of Technology showed that concentrates contained 0.125 ounces platinum and 0.275 ounces palladium per ton.

Almost all of the twelve specimens from the Key West Mine submitted to us contain pyrite and chalcopyrite in considerable amount but as far as could be observed no pyrrhotite is present. The specimens vary greatly in appearance, some being in the main

greenish, granular igneous rocks; others dark grey, hard and quartzose; others soft and chloritic or largely made up of a dolomitic carbonate. All of them contain about the same association of sulphides.

The determination of the sulphides was made by metallographic methods. The relation between sulphides and gangue were studied in thin sections.

COMPOSITION OF THE ORES AS SHOWN IN THIN SECTION.

The freshest material is a dark green granular hornblendite almost free from decomposition. The size of grain is about 1 to 2 millimeters. The sulphides, as seen in the specimen, appear to fill the interstices between the silicates.

In thin section the grains are stout prismatic or equidimensional and now consist mainly of pale greenish brown hornblende with normal extinction and slight pleochroism. There are a few grains of augite remaining and some indication that a rhombic pyroxene was also originally present. The rock crystallized as a pyroxenite and the change to hornblende was evidently a late magmatic process. Close to the sulphides the silicate changes abruptly to a colorless amphibole which often has exactly the same optical orientation as the adjoining greenish hornblende. The sulphides fill triangular interstices or druses in the rock and consist of pyrite, chalcopyrite and pentlandite; the latter containing grey reticulating veins of "polydymite." There are also a few grains of magnetite. In many places the sulphides are molded on the prisms of pyroxene or amphibole, retaining the prismatic striations of these minerals. In other places the sulphides distinctly corrode the silicates.

This specimen is held to prove the late magmatic origin of the ore minerals. We believe that they formed part of the magma of the dike and consolidated as the last of its minerals of igneous origin.

The other specimens show, however, that alteration by hot waters continued after the congealing of the dike. This alteration is expressed in extensive development of chlorite with some

serpentine and talc. The chlorite is sometimes replaced by quartz. One specimen contains about 50 per cent. quartz in large individuals and residual chlorite with pyrite grains averaging 0.2 millimeters in diameter. Rutile and probably a little molybdenite were also observed.

The last process of deepseated origin, which affected the ore, consisted in dolomitization. The chlorite is sometimes almost wholly converted into carbonate; one sample, for instance, containing about 75 per cent. of this calcium-magnesium carbonate.

Oxidation resulting in partial alteration of pyrite and chalcopyrite to limonite is observed in several specimens.

The history of the ores then comprises:

1. A late magmatic stage when most of the sulphides were introduced.
2. A subsequent hydrothermal stage during which the original silicates were replaced by chlorite, serpentine talc, quartz, and dolomite but during which the sulphides were not greatly changed. It is possible, however, that the introduction of the " polydymite " belongs in part to this stage.
3. A period of oxidation to a depth extending, at least, to the water level, that is about 200 feet below the surface. During this period the pentlandite was oxidized to nickel sulphate which descended in the deposit and probably produced sulphide enrichment by replacing pentlandite by " polydymite," which is the richer sulphide. This at least is the view that is tentatively held by us though we have no field evidence, with which to corroborate it.

COMPOSITION OF THE SULPHIDES AS SHOWN IN POLISHED SECTION.

Polished sections prepared from the samples submitted for examination revealed the presence of the following ore minerals: Pyrite FeS_2, Chalcopyrite $CuFeS_2$, Pentlandite $(FeNi)S$ normally 36 per cent. nickel, " Polydymite " Ni_4S_5(?) normally 59.4 per cent. nickel (calculated), Sphalerite ZnS, Magnetite Fe_3O_4.

Pyrite.—This mineral occurs scattered widely throughout all of the material examined and usually in the form of interstitial fillings molded about and sometimes corroding the primary gangue minerals. It is usually much fractured and subjected to all degrees of replacement by chalcopyrite and possibly pentlandite. In such cases it is found as irregular residual masses in the younger minerals. (See Pl. VIII., *B.*) A few highly polished areas of pyrite appear to be abnormally white as viewed under the microscope, and it was at first thought that it might be a nickeliferous variety. However, carefully applied microchemical tests with dimethyl glyoxime failed to reveal any nickel in this pyrite.

Chalcopyrite.—This is the most abundant mineral in the samples examined, being found in every specimen and usually in large amount. It is comparatively coarse in size and contains residual pyrite as well as veins of "polydymite" and pentlandite, the areas of the latter sometimes equalling the chalcopyrite in extent. (See Pl. VII., *C.*) The chalcopyrite is entirely normal and tests applied showed it to be free of nickel.

Pentlandite.—This cream colored nickel mineral is present in all except one specimen examined and in some localized areas is equally abundant as the chalcopyrite with which it is closely associated and which it has replaced, as indicated by the prevailing structural relations. In a few cases networks of veinlets in fractured pyrite are filled with pentlandite, but since it is very common for the chalcopyrite to occur in this manner it is possible that these are cases of replacement of the chalcopyrite which originally filled the veinlets. It has been stated in preceding paragraphs that no nickel could be detected in the pyrite or chalcopyrite. On the other hand, large amounts of nickel were revealed by tests applied on the pentlandite. Pentlandite which somewhat resembles pyrrhotite is, however, easily distinguished from it by microchemical methods.

"Polydymite."—This rich nickel mineral was observed in two specimens, where it occurred in abundance, replacing both pentlandite and chalcopyrite (Pls. VII., *A* and VIII., *A, B, C*). It has developed chiefly by the replacement of pentlandite. The

photographs show all stages in this replacement from minute veinlets of "polydymite" cutting pentlandite to masses of the former with small residual patches of the latter. In one place it was distinctly observed that these veinlets occasionally penetrate into the chalcopyrite at the contact between it and pentlandite. The "polydymite" is slightly harder than the chalcopyrite, but is very brittle and during polishing chips out readily.

The mineral has a violet grey tinge in polished section and is tarnished blue with slow effervescence by dilute nitric acid. Other reagents are negative except that hydrochloric acid applied to the mineral turns green. It has been termed "polydymite" in this report due to its similarity in appearance and reactions to one of a mixture of nickel sulphides from the Vermilion Mine, Ontario, analyzed by F. W. Clarke and Charles Catlett.[2] At that date these authors had no means of knowing that they were not dealing with a pure material and they proposed the formula Ni_3FeS_5 for their mineral. Examination of material such as they analyzed reveals a nickel-iron sulphide (pentlandite or an undescribed mineral very closely related to it) replaced by a network of veinlets of a violet grey mineral identical with the mineral termed "polydymite" in this report. In the specimens from Key West it is present in sufficient quantity to account for a large proportion of the nickel shown by the analyses if it is a pure nickel sulphide similar to the original polydymite Ni_4S_5, described from Westphalia, Germany. The mineral gives a strong nickel reaction with dimethyl glyoxime; unfortunately it proved impossible to obtain it pure enough for analysis. It contains little iron and no bismuth or arsenic.

Sphalerite.—The zinc sulphide occurs very sparingly as a primary mineral associated with chalcopyrite. It is not sufficiently abundant in the specimens examined to be of any importance in a commercial consideration of the ore.

Magnetite.—This iron mineral is also present in minor amounts only. It seems to be rather uniformly distributed throughout both the gangue and sulphides.

[2] *American Jour. Sci.* (3), vol. 37, 1889, p. 372.

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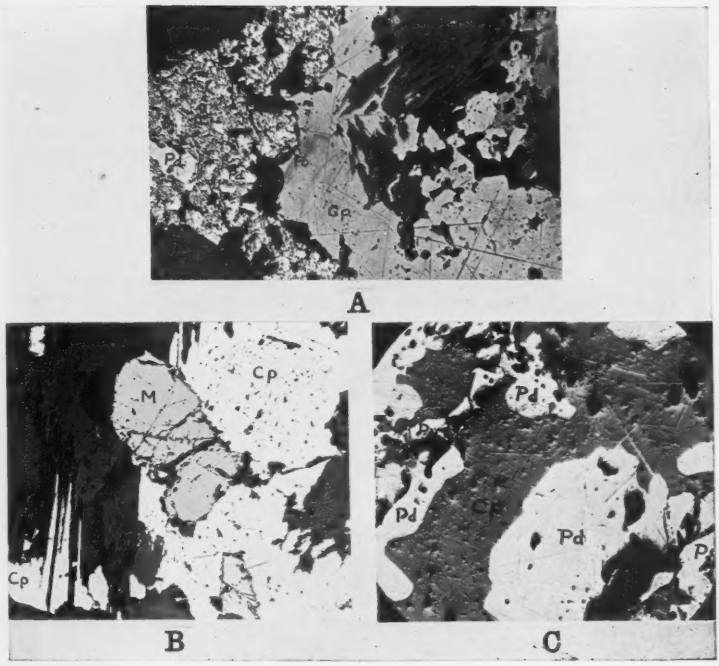
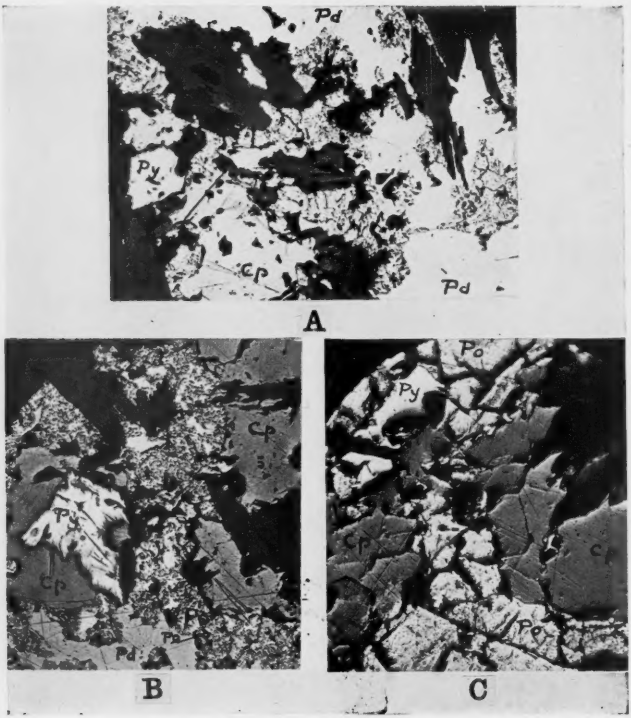


A. Corroded remains of magnetite crystal (M) in gangue (G). Chalcopyrite (Cp) molded about gangue and replaced by pentlandite and polydymite. Residual grains of pentlandite (Pd) remain in younger polydymite (Po). × 65.

B. Prisms of primary gangue minerals (black) molded about grain of magnetite (M). Chalcopyrite (Cp) molded about projecting needles of hornblende. × 83.

C. Residual pyrite (Py) in chalcopyrite (Cp) which is replaced by fresh pentlandite (Pd), illustrating the characteristic appearance of sulphide ore in which enrichment by polydymite has not begun. × 129.



A. Chalcopyrite (Cp) replaced by pentlandite (Pd), which is being replaced by polydymite (Po). Note typical secondary structure shown by distinct veinlets of polydymite in pentlandite. × 87.

B. Pyrite (Py) residual in, and partly replaced by chalcopyrite (Cp), which is cut by veins of pentlandite (Pd) and polydymite (Po), the former in process of replacement by the latter. × 87.

C. Residual pyrite (Py). Chalcopyrite (Cp) cut by a vein of polydymite (Po), illustrating most advanced enrichment. Primary pentlandite entirely altered to polydymite. × 136.

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GENESIS OF THE ORE MINERALS.

Magnetite, as indicated by its uniform distribution throughout both gangue and sulphide, and by the manner in which primary gangue crystals are molded about it, was the first mineral to separate from the magma (Pl. VII., *B*). Pyrite, which is residual in, and older than the other sulphides, has formed after the solidification of the primary gangue minerals. It occurs associated with the other sulphides and is not distributed uniformly as is the case with the magnetite. The presence of pyrite as a mineral of magmatic origin is worthy of note, as is also the absence of pyrrhotite. Chalcopyrite next separated out, surrounding and replacing the older pyrite. It is commonly observed molded about absolutely sharp and unaltered crystals of the primary gangue minerals (Pl. VII., *B*, VIII., *A*) indicating that it formed during the solidification of the magma rather than by deposition of solutions in fissures, in which case considerable alteration and formation of new gangue minerals would be expected. The separation of the nickel appears to have occurred in the final stage of solidification. Pentlandite, the primary nickel mineral, replaces chalcopyrite quite extensively in practically all of the material examined. Minor amounts of sphalerite were likewise formed during this last primary stage.

At a later period the ores were exposed to the action of descending waters which dissolved nickel and precipitated it as "polydymite" when reduced by the pentlandite in lower levels. The development of this rich nickel sulphide in marginal and reticulated replacements suggests to us a case of secondary enrichment of nickel and may possibly have an important commercial significance. The degree to which this enrichment has proceeded and the depths to which it extends can not be determined in examination of specimens.

REMARKS ON POLYDYMITE.[3]

There can be no reasonable doubt that the "polydymite" described above is a pure or almost pure nickel sulphide. Whether

[3] For the following concluding remarks the senior author must bear the sole responsibility.

it is identical with the normal polydymite of mineralogy is another question.

It is certain that our "polydymite" is identical with the mineral known under this name from Sudbury, Ontario. The mixture of this mineral with pentlandite and a little pyrite and chalcopyrite has, as stated above, been analyzed by Clarke and Catlett,[4] and has been given the formula Ni_3FeS_5. That this is a mixture is evident; Tolman and Rogers [5] describe this ore in polished sections as follows:

> In Fig. 37 is represented a supposed specimen of polydymite from the Vermilion Mine. This contains pyrite in the form of veinlets. . . . The relation of the polydymite to the magmatic sulphides is not entirely certain, but the examination of a very fresh specimen suggests that the Sudbury polydymite is a mixture of three minerals: Pentlandite, an unknown violet grey mineral and the true polydymite. The polydymite and the violet grey mineral are probably due to the breaking down of the pentlandite.

I can not confirm from my observations the occurrence of true polydymite from this place but that the violet grey mineral and the pentlandite are the principal components is certain. Chalcopyrite is always present as well but that mineral was eliminated in the calculation of the analysis by Clarke and Catlett. It is probably impossible to isolate this "polydymite" for there will always be more or less pentlandite present. Most of my specimens contain about equal quantities of pentlandite and "polydymite."

The question now arises whether this mineral is identical with the normal polydymite from Grüneau, Westphalia. The identity of the "polydymite" from Key West, Nevada, with that of Vermilion Mine, Sudbury, is beyond doubt. The mineral described under the name of polydymite in the tables of Davy and Farnham [6] is that from Vermilion Mine and Key West. That described by Murdoch [7] is the normal mineral from Grüneau. The

[4] Clarke, F. W., and Catlett, C., *American Jour. Sci.* (3), vol. 37, 1889, p. 373.

[5] Tolman, C. F., and Rogers, A. F., "A Study of the Magmatic Sulphide Ores." Leland Stanford Univ. Publ., University series, Stanford University, 1916, p. 33.

[6] "Microscopic Determination of the Ore Minerals," New York, 1920, p. 87.

[7] Murdoch, J., "Microscopical Determination of the Opaque Minerals," New York, 1916, p. 82.

polydymite from Grüneau is steel grey, decidedly harder than chalcopyrite and effervesces extremely slowly with dilute nitric acid. The other reagents are negative. It is not very brittle. The mineral is very resistant to alteration; polished sections of it retain their luster for long time. Type specimens from the U. S. National Museum and from Krantz, in Bonn, show no alteration and an association with chalcopyrite and siderite in undoubtedly primary ore.

The "polydymite" from Vermilion and Key West is distinctly violet grey, a color shared by no other mineral. It has about the same hardness as chalcopyrite. It is extremely brittle. It alters rapidly in the air to a pulverulent mass and polished sections tarnish quickly. It effervesces somewhat more readily than the Grüneau species, but otherwise agrees with it in reactions used for work on polished sections. These differences indicate, I believe, that the two species should be separated.

Regarding the composition of the "polydymite" from Vermilion we have of course the analysis of Clarke and Catlett; that the material contained admixed pentlandite may be regarded as certain. The following table shows the relations between the various minerals.

TYPICAL ANALYSES OF NICKEL SULPHIDES.

	S.	Ni.	Co.	Fe.	Gangue.	Total.
1. Polydymite $Ni(Fe.Co)_4S_5$	41.09	54.30	0.63	3.98		100
2. Pentlandite	33.42	34.23	0.85	30.25	0.67	99.42
3. "Polydymite"	41.35	43.18		15.47		100

1. Laspeyres, *Journal f. Chem.*, 1876, 14, p. 397. Grüneau Ni_4S_5.
2. Penfield, *American Jour. Sci.*, (3), vol. 45, 1893, p. 494. Sudbury NiFeS. *Trans. Min. Eng.*, vol. 34, 1904, p. 21.
3. Clarke and Catlett, *American Jour. Sci.*, (3), vol. 37, 1889, p. 373. Vermilion Mine. Ni_3FeS_5.

While it is true that even the purest "polydymite" from Vermilion Mine appears to contain some iron it is certain that the figure given by Clarke and Catlett—15.47 per cent.—is too high.

If we assume that the pure "polydymite" contains no iron the percentages in the mixture belonging to pentlandite would be

S 16.8 Ni 17.5 Fe 15.5 = 49.8

and the mixture would contain about 50 per cent. pentlandite. This would leave for "polydymite"

S 24.55 Ni 25.68 = 50.23

which would indicate a molecular proportion of S : Ni = 0.77 : 0.43 or not far from 2 : 1 or NiS_2.

It is realized of course that this conclusion rests on two assumptions: That the polydymite is practically free of iron; and that the mixture contained pentlandite and polydymite in equal proportions. Neither of these assumptions is exact.

Thus far no NiS_2 is found in nature, and it has even been argued that it could not exist because it can not be obtained by the melting together of nickel and sulphur.[8]

The calculation may stand for what it is worth. At any rate it has been shown that the "polydymite" from Vermilion, Ontario and Key West, Nevada, is not identical with polydymite; that it developed very late in the mineral succession; and that its mode of occurrence suggests very strongly the action of descending or "supergene" nickel solutions on pentlandite and chalcopyrite. It might conveniently be designated as *violarite* from the latin adjective violaris, alluding to its violet grey color in polished section.

The known nickel sulphides then comprise the following species:

Beyrichite NiS. Same composition as millerite but differing specific gravity. Laspeyres holds all millerite to be paramorphic after Beyrichite.

Millerite NiS. Ni 64.7%. Rhombohedral. In part secondary by supergene waters. Thus from Lancaster, Antwerp, Sudbury. Reported to occur as ore at Benton, Arkansas.

[8] I. and L. Bellucci, *Chem. Abstr.*, 1909, p. 293.

Polydymite Ni_4S_5. Ni 59.4%. Isometric. Siegen district, Westphalia.

Violarite NiS_2(?). Ni 48%. Vermilion Mine, Sudbury; Key West Mine, Nevada. Occurs as ore mineral of some importance.

Pentlandite (Fe, Ni)S. Ni 34.23%. Isometric. Many occurrences. Most important nickel sulphide.
Nevada. Occurs as ore mineral of some importance.

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SOME METHODS FOR HEAVY MINERAL INVESTIGATIONS.

R. D. REED.

ABOUT 75 years ago H. C. Sorby,[1] a young British geologist, applied to the study of sedimentary rocks the thin section and the nicol prism. These devices were later applied by Sorby and others to the investigation of igneous rocks with eminent success. In spite of its earlier start, however, for a variety of reasons the petrographic study of the sedimentary rocks has made comparatively slow progress. Now, when there are many evidences of an increasing interest in the subject, progress seems likely to be delayed by the confusing variety and complexity of the methods that are recommended for the different steps in an investigation. With the aim of showing how much may be accomplished by very simple methods if they are carefully adapted to the particular circumstances attending an investigation, it is proposed to give in the following pages, along with some general remarks about the aims and possibilities of sedimentary petrography, a discussion of the methods adopted in one fairly extensive investigation of a problem in that field.

This problem related to the possibility of making correlations for short distances in certain Tertiary formations of California by a study of "heavy mineral" residues.[2] The methods used are of course only in part original. They were adopted after a study of the available publications in English, German, and French; after a testing and comparison of the more promising methods in the laboratory; and after repeated attempts to devise new methods for the operations that seemed to need them.

[1] H. C. Sorby, "On the Microscopical Structure of the Calcareous Grits of the Yorkshire Coast," *Quarterly Journal of the Geological Society*, VII., page 1, 1851.

[2] The work was financed by the Stanford Petroleum Research Fund, a sum of money contributed by several oil companies for the purpose suggested in its name, and was carried out in the Petroleum Laboratory of the Department of Mining and Metallurgy of Stanford University. A discussion of the results of the investigation is in preparation.

A few of the more important published discussions of sedimentary petrography and its methods are given in a footnote.[3] The "Introduction" by Professor Cayeux is the most important book that has appeared on the subject. The best account in English, that of Dr. Holmes, while less thorough and more of a compilation than Cayeux's discussion, is instructive and exceptionally well written.

SAMPLING.

In a complete discussion of the methods used in heavy mineral investigations, the subject of sampling would have to be treated at length.[4] Here it may suffice merely to call attention to its importance. A small fragment of a sedimentary rock is likely not to be typical of the whole bed from which it comes. This fact is indeed of fundamental importance; one of the chief reasons, no doubt, for the slow development of the whole subject of sedimentary petrography. The task of securing samples for any investigation must therefore be undertaken with due care and consideration. Students of coal have perfected a method of taking a sample that is representative of the whole stratum. Quite as much effort as that method demands is frequently needed in the taking of samples of other sedimentary rocks.

In the study of well samples, with the taking of which the student has often little to do, he must at least keep in mind their limitations, and draw only such inferences from them as are clearly justified. The value of such samples depends obviously upon so many factors as to make a satisfactory discussion impracticable in this place.

[3] Cayeux, L., "Introduction à L'Étude Pétrographique des Roches Sedimentaires," Paris, 1916.

Holmes, A., "Petrographic Methods and Calculations," pages 1–230 (now published separately as Part I.), London, 1921.

Milner, H. B., "An Introduction to Sedimentary Petrography," London, 1922.

McCaughey and Fry, "The Microscopic Determination of Soil-Forming Minerals," Bulletin 91, U. S. Bureau of Soils, Washington, 1913. (Out of print.)

[4] For some interesting suggestions, see Milner, *op. cit.*, page 15.

PREPARATIONS OF SAMPLES FOR STUDY.

Thin Sections or Fragments?—The preparatory processes to which the samples will be subjected vary immensely according to one's choice of thin sections or mounted fragments for microscopic study. In spite of its almost exclusive use by many petrographers, the thin section is inadequate in heavy mineral investigations. The difficulty is that the rarer heavy minerals are usually scattered so thinly among the quartz and feldspar grains of a sedimentary rock that a single thin section is certain not to show even a single grain of each of them. It is only by concentrating the rare minerals from a comparatively large volume of the rock that one may secure a sufficient quantity for satisfactory study. For this reason the preparation and study of thin sections, although they are useful in some phases of a heavy mineral investigation, are not further discussed in this paper.

General Considerations.—In all the work of preparing the heavy minerals for study, a few guiding principles may well be kept in mind. In the first place, since the heavy minerals owe their universal presence in sediments to the fact that they are all but indestructible, they may be trusted to survive treatment so drastic as utterly to destroy less stable minerals and most organic remains. For this reason one may often advantageously use methods that would not serve at all well for general investigations in sedimentary petrography.

In the second place, because of the high specific gravity of these minerals, whence comes the possibility of securing them, as discussed farther on, by panning, they are very easily lost in carelessly pouring grains in suspension from one vessel to another. The loss is harmful not only because it reduces the size of the "crop" in the sample, but also because the lost grains are likely to become mixed with those from another sample. The danger of "salting" samples, in fact, can not be too constantly kept in mind, either in choosing methods or in applying them.

Thirdly, in all possible instances one should plan to handle

from ten to twenty samples together. The economy in time and effort resulting from a consistent application of this suggestion is surprisingly great. By means of it one can usually reduce the average time required in preparing for study a fragmental sample much below that required, for example, in making a thin section.

Finally, the investigator must not let the number and complexity of the methods advocated by different petrographers distract his attention from his own object in any given case.

To Break Down the Samples.—With a good many types of consolidated rock, the mere task of reducing the sample to its constituent grains is a difficult one. The simpler types of rock are, many of them, easy to disintegrate. A muddy cement yields to prolonged soaking in water, calcareous material to dilute acid, ferruginous to hot acid, and soluble silica to an alkali. In spite of these well-known generalizations, many rocks are too refractory for any desirable, simple methods. The experience gained in trying to break down a moderately indurated specimen of diatomaceous shale will illustrate the matter.

Coarsely crushed and treated with dilute hydrochloric acid, this rock effervesced slowly, but only from some included foraminifera; with boiling acid there was no further result; with dilute, then concentrated, and finally boiling caustic soda, there was no apparent result at all; heating to redness and plunging into cold water produced no effect; soaking for months in water and vigorous brushing with a tooth brush softened and disaggregated the surface of a sample slightly, but produced too little powder for study. Treatment with hydrofluoric acid would no doubt be effective, since the heavy minerals are less soluble than quartz, but the treatment appeared too bothersome and expensive for routine use. The method finally adopted makes use of crushing to about the fineness of the average detrital grains—very fine crushing is undesirable for several reasons—panning to eliminate most of the light, siliceous material, and then further treatment of the detrital grains.

It may be said in conclusion that the breaking down is to be accomplished by careful consideration of the specimen in hand and use of all the available resources. Imitate nature's chemical weathering, so far as possible; if that fails, imitate her mechanical weathering.

To Remove Cement and Mud.—The separation of detrital grains, as well as their study, is hindered by coatings of cement, especially of ferruginous cement. In making heavy mineral investigations of many kinds of rock it is therefore advantageous to boil the disintegrated sand or silt in hydrochloric acid of sufficient strength to remove such coatings. In spite of published assertions to the effect that this treatment destroys apatite, hypersthene, and other minerals of a similar degree of stability, in several experiments these minerals were not visibly affected by boiling for as much as an hour in 50 per cent. acid. However inadvisable it may be in making a thorough mineralogical study of a sample, then, in the study of the heavy minerals alone the treatment has abundantly justified its use.

To eliminate the mud from the sand and silt, the most satisfactory method makes use of repeated suspensions and decantations. Stirred in a beaker of water, the grains are allowed to subside in a beaker until only the finest mica flakes may still be seen in suspension. It is also well, at least for a beginner, to make occasional microscopic examinations to determine the sizes of grains left in suspension at the end of 30, 60, and more seconds. As soon as the water contains only mud in suspension, as judged by one of these methods, it may be poured carefully away. After a few repetitions of the process, best carried out of course with several samples at a time, the cleansed grains may be placed in scorifiers and dried on a hot-plate.

Elutriation.[5]—In the early stages of the investigation at Stan-

[5] For a detailed account of elutriation and its uses, see either of the following:

H. W. Wiley, "Principles and Practice of Agricultural Analysis," second ed., vol. 1, Soils, Easton, Pa., 1906.

H. A. Baker, "On the Investigation of the Mechanical Composition of Loose Arenaceous Sediments by the Method of Elutriation," etc., *Geol. Mag.*, 1920.

ford, some use was made of a Schöne elutriator to free the grains from mud. Among the many interesting facts learned from its use, however, the most important is that for ordinary mineralogical research, elutriation is time-consuming and all but useless. In soil investigations, and in making detailed analyses of fine sediments, it doubtless has an important place.

Screening.—The important facts in regard to screening, as related to heavy mineral investigations, appear to be two. In the first place, the use of a screen so fine that it can not be easily and thoroughly cleansed is a prolific source of confusion. The difficulty may be avoided either by using a new piece of fine cloth for each separation, or by screening a sample other than that reserved for mineralogical study. In the second place, except for the screening away of very coarse grains or pebbles, the use of screens for mineralogical analyses is often as unnecessary, though never so time-consuming, as the use of an elutriator. Too often the screening of the grains serves no purpose except to multiply the succeeding operations by the number of screens used plus one.

Separation of the Rarer from the Common Minerals.—When the samples have been disintegrated, cleansed, and dried, they constitute a set of sands and silts, in everything but the absence of mud and water, like the sands and silts originally deposited. The further procedure involves the separation of the common minerals that might have been derived from many sources, from the less common minerals of more restricted primary occurrence. The most useful basis of separation is the difference of the two classes in specific gravity.

Panning.—Panning, the oldest and best-known method of separating minerals in accordance with their specific gravities, is often useful in heavy mineral investigations.[6] Its chief drawbacks are that it separates by weight rather than by specific gravity, and that it is not sufficiently independent of the shapes of grains. Small grains of heavy minerals will be mixed in the residue with larger grains of lighter ones, while flaky grains of

[6] Cf. R. H. Rastall, "Some Points in Sedimentary Petrography," *Geol. Mag.*, page 33, 1923.

the heavy minerals will be eliminated along with more equidimensional grains of lighter ones. In addition to these drawbacks, the latter of which is shared even by the bromoform method, the results of panning depend so much on the skill of the individual experimenter that the method can hardly be recommended without qualification for general use.

In dealing with a silt or fine sand of uniform texture, one may dry the partially panned residue, and then extract from it all the magnetic heavy minerals by using an electromagnet. The non-magnetic residue, if panned until only a few grains are left, will contain most of the non-magnetic heavy minerals, with only a little quartz and feldspar. For this and other purposes, skill in the use of a pan will be needed sufficiently often to make it worth acquiring.

Separation by Means of Heavy Liquids.—In spite of some theoretical drawbacks, bromoform appears to be the best of the liquids that have been suggested for the purpose of floating off the light minerals from the heavy residue. Commercial bromoform often has a specific gravity less than that of quartz, but may, by boiling, be concentrated to any desired density less than about 2.9. A heavy mineral, then, is simply one that sinks in bromoform,—a definition of practical value.

In regard to the very numerous separators that have been devised for use with bromoform, a good policy appears to be to use no one of them unless it is clearly necessary for the particular problem in hand. The method most used at Stanford, a modification of one proposed by Cayeux,[7] makes use of only the simplest apparatus.

Making a Bromoform Separation.—In using this method, one or more small spoonfuls of the sand may be scattered upon a quantity of bromoform in the bottom of a tilted evaporating dish of fairly large size. Because of the slight depth and large surface of the bromoform, the heavy grains fall quickly to the bottom of the dish. The bromoform, along with most of the

[7] Cayeux, *op. cit.*, page 66.

lighter grains, may then be poured into a filter which drains into an empty bottle. By one or two repetitions of the process, the heavy grains may be secured nearly free from admixed lighter ones. They must be washed free from traces of bromoform with benzol,—conveniently applied by means of a small wash-bottle,—dried, and either filed, or mounted at once.

With a little care in arranging the apparatus and in standardizing the procedure, this simple method gives astonishingly good results in much less time than is required in using even the simplest separatory funnel. The samples should of course be treated in series, and the various operations should be practiced until the operator becomes proficient. The whole procedure is capable, in fact, of being varied and improved almost without limit. It will abundantly repay a little effort and ingenuity on the part of the experimenter.

The Light Minerals of a Sample.—In any heavy mineral investigation, the quartz and feldspar grains should be examined with care. Some of them may possess peculiarities, even inclusions of heavy minerals, that render them quite as valuable for purposes of correlation [8] as the heavy minerals themselves. For this reason a portion of the light fraction, or of the cleansed, unseparated sample, should be filed for microscopic examination.

The Use of the Electromagnet.[9]—In addition to its use in completing separations by panning, as mentioned above, the electromagnet may be used to separate the fairly common heavy minerals, such as the amphiboles, the pyroxenes, and the opaque ores, from the rarer heavy minerals of most restricted primary occurrence, and hence is of greatest value in making correlations. If the former group is abundant, as in some California formations, its abundance may completely mask the relations of the more important minerals.

In using the electromagnet, as in screening, one should make

[8] Cayeux, *op. cit.*, page 199. W. Mackie, *Trans. Edin. Geol. Soc.*, VII., p. 148, 1896.

[9] For an excellent account of the construction and use of electromagnets, see Charles H. Warren, *Technology Quarterly*, p. 317, 1906.

sure that the results are likely to justify the multiplication of later manipulations that its use entails. To use the electromagnet simply as part of a rigid routine is likely to have often as its chief result the lengthening of the task of preparing samples. Even when the electromagnet is clearly needed, moreover, it will not always give satisfactory results. Owing to variations in the iron content of minerals of the same species, and to variations in the quantity of magnetic inclusions in different grains, the same mineral is likely to be found in nearly all the magnetic crops from a sample.

Other Methods.—The other methods of separating heavy minerals are of such restricted application that they may be neglected entirely until circumstances arise that necessitate their use.

The Problem of Mounting.—With the residue of heavy minerals in hand, separated into magnetic or other crops if necessary, one is ready to consider the problem of mounting. Two methods are available: one to mount in balsam a part or all of each crop, the other to file the crops in envelopes for future use with non-permanent preparations. Each method has advantages for special purposes. In the prosecution of research problems, the permanent preparations have the advantage of being the more useful as evidence. If the microscope in use is provided with a mechanical stage, one can note the position of an interesting grain and turn to it easily at any later time. If a sample contains any unusual minerals, however, there is a great advantage in using non-permanent preparations, from which an unknown grain may be abstracted for the making of refractive index, or other, determinations. Because of this advantage and the great economy in time that results from the use of the non-permanent preparations, it is likely to prove best to use them almost exclusively in commercial work.

Permanent Preparations.—If permanent slides are to be made at all, experience dictates that they should be made as nearly perfect as possible. A poorly made preparation is an annoyance, and a well-made one a source of pleasure, during the whole of

the comparatively long time that they are likely to be under observation. After a little practice, the experimenter may use the following method to make from 6 to 10 perfect preparations at a time. Most of the manipulations may be executed in less time than is required to read about them.[10]

The first operation is to clean the slides so perfectly that a drop of water may be spread to a thin film on one of them. The result may often be secured by applying a drop of pure alcohol and rubbing with a dry, clean cloth. A possibly better method is to immerse 50 or more slides for 20 minutes in a hot, 30 per cent. solution of sodium carbonate, wash in distilled water, immerse for 15 minutes in a solution made of equal parts of water and nitric acid, wash again, dry, and wrap in paper until needed.

The number of slides to be handled at a time—only one at first, of course—may be first marked by means of a diamond with the numbers of the samples they are to illustrate. In the center of each slide is placed a drop of distilled water—tap water gives myriads of minute crystals that spoil the appearance of a preparation—and spread with a glass stirring-rod to a film a half-inch or so in diameter. Sprinkle the grains, the finer ones if other considerations permit, in the film of water until they appear rather thickly strewn. If the sprinkling is uneven, the grains may be spread with the point of a sharpened match or a mounted needle. If the water film is sufficiently thin the grains will stay where they are put. Otherwise, during the evaporation of the water they must be constantly spread until the water film becomes too thin to allow them to move about in it. The evaporation of the water is hastened by putting the slides on a hot-plate, preferably in such a way that one end of each slide projects beyond the edge so as to remain cool enough for comfortable handling. As soon as the water has evaporated, the grains are firmly fixed in their positions. The slides may be tilted or shaken without losing them.

With the hot-plate on "low," a drop of balsam may be placed in the midst of the grains. Becoming fluid, it will flow among

[10] For a method similar in many respects, see Cayeux, *op. cit.*, page 80.

and over them without disturbing them. The temperature of the hot-plate must be adjusted so that bubbles come from the balsam, slowly at first, and later not at all. Rapid heating or long-continued over-heating discolors the balsam and renders it so highly brittle that it will not withstand ordinary usage. Slow heating, as recommended, until the balsam will crack between the teeth, or somewhat longer for that matter—since the balsam does not need the maximum of tenacity in these preparations so much as in thin-section grinding—keeps it colorless and sufficiently tough.

When the balsam is properly cooked, a cover-glass may be put on without a single bubble under it if directions are followed: First, remove all bubbles from the balsam; then put the slide on a smooth, cold piece of iron so as to cause rapid cooling. During the cooling, stick one edge of a cover-glass down in the margin of the circular area of balsam. Next place the slide on the hot-plate again. As the balsam softens, the cover-glass will gradually sink to a horizontal position without any bubbles under it. The slide may then be put once more on the cold piece of iron, and the cover-glass gently pressed down. The excess of balsam, which forms a ring at the edge of the cover-glass, may be broken away with a knife. The remaining traces should then be removed with some solvent, such as xylol.

A Method of Filing.—There is an obvious advantage in being able to file together loose detrital grains, mounted grains, and all data in regard to them and the samples from which they were separated. Cards four by six inches in dimensions serve well for the data. For the loose grains, ordinary envelopes, three and a half by six inches, with the two lower corners pasted down, have proved satisfactory. If envelopes of the same size as the cards could be purchased they would be slightly better. For the permanently mounted grains, four-by-six cards with a row of pockets across the back serve admirably. By special arrangement at a print-shop, they may be secured in lots of 500 or 1,000, and kept for use as needed. They are considerably cheaper than the old-fashioned slide-boxes, and are more convenient in every way.

SOME REMARKS ON PETROGRAPHIC METHODS.

Limitation of Treatment.—A satisfactory brief treatment of the microscopic methods that are applicable to fragments is even more impossible to give than a similar treatment of the preparatory methods. It will be necessary, therefore, to limit the discussion that follows to some of the more difficult points, and to points about which there has been controversy.

The Microscope.—In the study of fragments one may use either a binocular microscope or an ordinary polarizing microscope, or both. The binocular microscope gives a better notion of the shapes of sand grains, but no notion at all of the pleochroism and of many other important properties. With the polarizing microscope, preferably of the type with rotating nicols, the student is much better equipped for that detailed study of the optical properties of a mineral that is often the price of an accurate identification. The impossibility of inferring anything in regard to the identity of a grain from its associates frequently makes such studies necessary.

Appearance of Fragments in Polarizing Microscope.—To the student accustomed to thin sections, the first glance through a polarizing microscope at a preparation of detrital grains is bewildering and discouraging. He sees no two grains that are certainly the same mineral, no one that is certainly identifiable. After a little study, however, he becomes able to see that after all some minerals tend to occur in grains with more or less characteristic shapes; that the variation in size among the grains does not prevent an estimation of their relief; that, in fact, the grains possess most of the properties possessed by the same minerals in thin sections. The one important exception is birefringence of determinable amount. The combination of varying and unknown thicknesses with unknown but not actually random orientation makes the birefringence as undeterminable as it is conspicuous. In a few months at most, however, one becomes able to identify fragments at least as readily as minerals in thin section, and often more certainly. The feat is possible even with

permanently mounted grains, but is always rather more easy and certain with non-permanent preparations.

Mounting Media.—For general use as a temporary mounting medium for heavy minerals, some liquid with a refractive index of about 1.65 is better than the more commonly used oils of lower index. Since refractive index increases with specific gravity, all the common heavy minerals have indices higher than those of quartz and feldspar. All of them accordingly have high relief in such media as cinnamon oil. Monobromnaphthalene, with an index near 1.67, splits the heavy minerals into two roughly equivalent groups, and has proved very satisfactory in practice. In the same way, ordinary Canada balsam mixed with piperine makes a good medium for permanent preparations of heavy minerals.

Immersion Fluids.—In addition to some medium for ordinary use, the investigator needs a set of immersion fluids to be used in confirming doubtful identifications. The set may start with a fluid of index 1.45 or less, although the heavy minerals themselves do not call for one lower than about 1.60. A set made by mixing in the proper proportions ethyl valerate, refined petroleum, monochlornaphthalene, and methylene iodide has proved satisfactory for minerals with an index below 1.74. For those with higher indices various resinous media are available.[11]

To Isolate an Unknown Grain.—Rare detrital grains are usually found among a large number of other grains of several species. Isolation of an unknown grain is often desirable, and may be readily accomplished. Using a mounted needle, and working under a low power of the microscope, one can move the grains about until the unknown grain is lying untouched by its neighbors. Placing a minute quantity of viscous balsam on the needle point, and poising the needle just above the unknown grain, one dips it quickly down toward the grain and withdraws it before the immersion fluid has time to dissolve the balsam. Dipped into a

[11] Immersion media are well discussed in the following: Larsen, E. S., "The Microscopic Determination of Nonopaque Minerals," U. S. Geol. Survey Bull. 687, pp. 12–22. Merwin, H. E., "Media of High Refraction for Refractive Index Determinations with the Microscope, *Wash. Acad. Sci. Journal.*, vol. 3, pp. 35–40, 1913.

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drop of xylol on another slide, the grain will immediately be set free from the balsam. Upon the evaporation of the very volatile xylol, the dry grain may be immersed in another fluid for further study.

Determination of Refractive Index.—In determining the refractive index of a grain with reference to that of an immersion fluid, both the Becke method and the method of inclined illumination are useful. If, as often happens with deeply colored grains, neither method gives conclusive results at first, the grain may be powdered by pressing it between two slides.

Other Means of Indentification.—Refractive index determinations are commonly made, of course, only in the case of difficult or unusual minerals. Most grains are readily identifiable by means of other criteria. A knowledge of optical mineralogy in general, and of the optical properties of the heavy minerals in particular, is of course a prerequisite to a successful application of these criteria. To point out some of the principles, and to mention a few useful devices, may nevertheless be worth while.

It has been shown above that with mounted grains birefringence is of little use as an aid to identification. Some other properties, however, are more useful than in thin sections. Because of the greater average thickness of the grains, color and pleochroism are commonly much more noticeable than in thin sections. These properties serve by themselves to distinguish instantly a considerable number of minerals, such as hypersthene, the amphiboles, and andalusite. The shapes of grains, even when modified by erosion, are likewise very characteristic for many minerals, such as kyanite, the amphiboles, zircon, and tourmaline.

The shapes assumed by fragments of a mineral are largely dependent, of course, upon the character and relations of the cleavage planes. If a mineral possesses one or more good cleavage planes, its fragments are likely to be almost always orientated in one or another of a few definite ways. The best cleavage of epidote, for example, is nearly perpendicular to an optic axis, while that of sillimanite is parallel to the optic plane. Because of these facts, many epidote grains give the characteristic inter-

ference figure with a nearly straight isogyre; sillimanite grains, on the other hand, rarely give a useful figure at all. With continued practice and study such facts as these become so fixed in the mind that one recognizes a grain of almost any common mineral, if not at a glance, certainly by the application of not more than one or two simple tests.

Orientation-Cleavage Diagrams.—While the more useful optical properties are thus becoming part of one's mental equipment, a few devices may be used to hasten the process. One of the best is the preparation of diagrams like the one illustrated in Fig. 39.

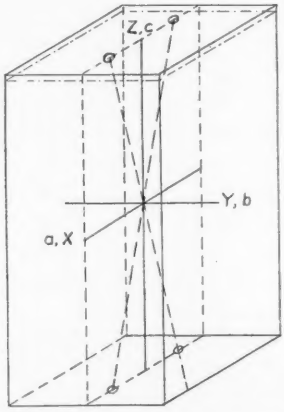

FIG. 39. Orientation diagram of topaz, with the perfect basal cleavage suggested by a line of dots and dashes. The diagram suggests that broken fragments, and therefore detrital grains, of topaz will usually be flakes so orientated as to give a biaxial positive interference figure showing the emergence of the acute bisectrix. Redrawn with modifications from Iddings, "Rock Minerals," page 293.

In the works of Iddings, Weinschenk, and other petrographers, diagrams needing only a little modification may be found for many minerals; from the data given in such works they may be prepared for other minerals. These diagrams suggest not only the shapes likely to be assumed by fragments of the minerals

represented, but also the optical properties to be expected of the fragments. They show, for example, whether the fragments of a given mineral may be expected to give an interference figure, and if so, what kind of figure.

A Set of Mounted Fragments.—Another device, so simple and so obviously useful that it is likely to be overlooked, is the making of permanent preparations of crushed fragments of the minerals which commonly occur as detrital grains. Of great value at the beginning of one's work with mineral grains, such a set is scarcely less useful during the whole course of it. Used with a set of diagrams like those discussed above, there is little danger of quickly exhausting the list of facts that may thus be learned about even the commonest detrital minerals.

Identification tables.—Many tables for the microscopic determination of larger or smaller groups of minerals may be found in the literature. Most of the tables include many minerals that are unnecessary, of course, and omit some that are important, from the standpoint of the student of detrital grains. Many of the tables, furthermore, are rather too consistently made to be readily used. After a little progress has been made in the study of grains, both objections may be obviated and much valuable experience gained at the same time by making one's own tables. The minerals actually of interest may then be included, along with the traits actually observed in them; and by making several tables with different properties as the basis of classification, one's attention may be forcibly directed to the important resemblances and differences among detrital minerals. One may, for example, profitably make a table of these minerals arranged simply according to the average refractive index; he may attempt to divide them into classes according to optical character, relief in a certain mounting medium, and so forth; and he may divide them into classes on the basis of such conspicuous traits as color and pleochroism, and typical shapes.

To Estimate the Percentages of Heavy Minerals.—In the preceding discussion it has been tacitly assumed that the investigator is not seeking accurate quantitative data. If such data are needed,

however, they may be secured without marked changes in the procedure that has been suggested. In a single operation, now to be described, experience has shown the advantage of making quantitative estimates in all cases. That operation is the estimating of the proportions of the various heavy minerals in a preparation. If one merely estimates the various species as "rare," "common," etc., he is likely to pass over relatively inconspicuous minerals without even seeing them, and to overestimate greatly the proportions of such bright-colored minerals as glaucophane. This error may be prevented by moving the stage slowly beneath the objective and counting the first hundred grains that pass the intersection of the cross-hairs. The number of grains of each species may be listed separately and the total kept by means of a pace-counter. Any desired degree of accuracy in the results may be obtained by counting enough additional hundreds of grains.

CONCLUDING SUGGESTIONS.

This discussion of a set of methods suitable for the attack of a particular petrographic problem will be concluded with expressions of opinion on two aspects of the more general field of research in sedimentary petrography. One of them concerns the advisability of looking for a standard routine for investigations in sedimentary petrography; the other, the probable future of that somewhat neglected branch of geology.

In regard to a standard routine, several facts may be considered. In the first place, the sedimentary rocks are almost infinnitely varied; as suggested above, the variations even in a single stratum may be such as to make adequate sampling a difficult task. Secondly, the purposes that may properly inspire an investigation into the nature of a group of sedimentary rocks are very numerous. The present paper, for example, deals with methods adapted to correlations by the study of heavy mineral residues. Correlation has also been attempted, however, by a microscopic study of lithological features of a more general nature, and of microörganisms. And of course, correlation itself is but one of many results that may properly be sought in petrographic studies.

In the third place, the history of petrographic research shows that in practice, though perhaps not always in theory, the principle that each sedimentary petrographer must devise many of his own methods has been recognized as valid. A reasonable conclusion from all these considerations appears to be that for a long time to come the preparation for a satisfactory petrographic study of a series of sedimentary rocks will not be reducible to a rigid routine of any kind. A clear understanding of the nature and geological relations of the rocks under study and of the end sought in each investigation, and untiring efforts to borrow or invent suitable methods—if there is a secret of success in this field, it may lie in some such combination as that.

The future of sedimentary petrography may be judged in the light of some interesting facts. In the first place, while the word petrography, if unqualified, still means to most geologists igneous petrography simply, the few researches that have been made in sedimentary petrography even in the United States have produced results of importance to general geology. In Europe, where the subject has been pursued more systematically for some years, this statement is true to a still greater degree. In the second place, the comparison of almost any recent geological report with one written twenty years ago will show that, at the present time, the need for more accurate petrologic data is recognized, even if the data are not always furnished. Finally, it may be permissible to quote an opinion recently expressed in an unsigned review, presumably by the Editor, in the *Geological Magazine* of London:[12]

> Of treatises on rock-slices there are legions, but sedimentary petrography is a much neglected field of far greater practical importance, and at the same time more difficult than the study of igneous rocks.

If this opinion is justified, even after a liberal discount, there must still be a vast stretch of interesting, unexplored territory ahead of the American sedimentary petrographer.

[12] *Geol. Mag.*, August, 1923, page 379.

PALO ALTO, CAL.

GEOLOGY OF THE BEATSON COPPER MINE, ALASKA.[1]

ALAN M. BATEMAN.

INTRODUCTION.

STUDENTS of ore deposits are acquainted with a baffling type of pyrite-chalcopyrite deposits that yield copper and often gold and occur as irregular bodies or lenses, often isolated ones, in schists or other metamorphic rocks. Their origin and the cause of their localization have usually proved perplexing to geologists and engineers and they yield little data upon which to plan intelligent exploration. The Beatson mine of the Kennecott Copper Corporation in Alaska is of this type, and the following pages pertain to a discussion of the deposit and its geologic setting.[2]

GENERAL FEATURES.

Location.—The mine is near the north end of Latouche Island, in Prince William Sound, Alaska, and is within a half-mile of tide-water. (Fig. 40.) The small town of Latouche is supported by the mine and is a regular port of call for ocean-going ships plying to southwestern Alaska. The mine, originally known as the Bonanza mine, but now called the Beatson, includes also the recently acquired Blackbird or Girdwood mine which lies some 2,000 feet north of the Beatson. These two properties will shortly be connected by underground workings. A prospect of lesser importance—the Chenega—lies between the two.

The Mine.—The Beatson mine, next to the Kennecott properties, is the largest copper mine in Alaska. Its productive capacity is about fifteen hundred tons of ore per day. A small

[1] Presented before Society of Economic Geologists, New York Meeting, May, 1924.

[2] The data here presented were obtained during brief examinations of the property extending over several seasons while in the capacity of consulting geologist to the Kennecott Copper Corp.

amount of mine product is shipped as direct smelting ore, but the greater part of the ore is milled at Latouche and the concentrates are shipped by steamer to the smelter at Tacoma, Washington. The mine is worked by means of a large open cut over 500 feet long and by underground workings of which there are nearly 10

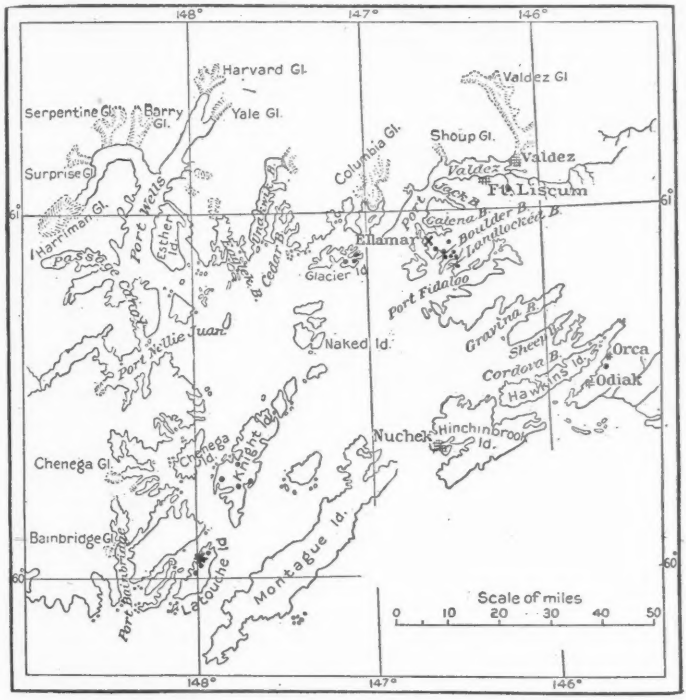

FIG. 40. Sketch map of Prince William Sound, Alaska, showing location of Latouche Island, and Beatson Mine (star). Modified from U. S. G. S.

miles, divided between five main levels. The mine is entered by tunnels and by a vertical shaft. The highest workings are at an elevation of about 350 feet above sea level and the lowest workings are 150 feet below sea level. Although the mine is close to

salt water and below sea level, the small amount of water pumped from the lowest level is quite fresh, due fortunately to a dip of the rocks from the land toward the sea.

The location of the property, so close to water transportation, has aided greatly its development. Originally discovered in 1897, it was worked at first only for its higher grade shipping ore. Mining was desultory, crude, and inefficient. When it was acquired by the Alaska Syndicate and later taken over by the Kennecott Copper Corporation, a mill was built, modern extraction methods were employed, and a vigorous development and mining program was started. Nearly 100,000,000 pounds of copper to date have been won from the property, and the present reserves show many years of life for the mine.

Climatic Setting.—The climate at Latouche is typical of the coastal section of southwestern Alaska. The annual precipitation is about 140 inches. The summers are cool, sunshiny days are few, and rainfall is abundant. The winters are never very cold; zero temperatures are rare, and the winter snow fall amounts to many feet. The temperatures are not conducive to rapid oxidation of the ore. Mining and milling proceeed throughout the year and the climate offers no barrier to winter transportation.

Topography.—A mountain range forms the backbone of Latouche Island and from it numerous spurs descend on either side steeply to the sea. Between the spurs are broad glacial cirques or basins with humpy floors, dotted here and there by ponds. These basins are transverse to the strike of the rocks and the outcrops of the harder beds form small ridges across the basins, so that in ascending from the sea toward the heads of the basins, one crosses successive ridges and flats. The main Beatson orebody lies on the flank of one of these transverse ridges in a northwestward-facing basin, and its site is marked by a prominent bluff, considerably higher and steeper than the surrounding ground. The prominence of this bluff is due to the greater resistance to erosion of the orebody itself and it is noteworthy that at either end of the orebody the hill falls away. Thus the topog-

raphy is in part at least an indication of the presence of the ore-bodies.

THE ROCKS AND THEIR STRUCTURE.

General.—The sedimentary rocks of Prince William Sound were subdivided by geologists who have worked in the field [2] into two large divisions—the Valdez and Orca groups. The Valdez group consists principally of graywacke and slate and is considered to be more metamorphosed and older than the Orca group. The Orca group consists of black slates, graywackes and slates, and greenstones, with subordinate conglomerates and limestones. Capps and Johnson [3] have subdivided the Orca group of the Ellamar district into divisions of lower black slates, lower slates and graywackes, greenstones, conglomerates, and upper slates and graywackes. They point out, however, that the Orca group varies greatly in character from place to place and that the subdivisions of one area may not hold for another.

A perusal of the literature indicates considerable difficulty in the distinction of some of the rocks of the two groups, and the reader is left in some doubt as to the accuracy of the separation in many places.

The age of the Orca group is considered by Grant and Higgins [4] to be probably Mesozoic. The same authors also state that the Orca group lies unconformably on the Valdez,[5] but Capps and Johnson [6] in their study of the Ellamar district found that the two groups are separated by fault contacts.

The part of Latouche Island known geologically is underlain by alternating beds of graywacke and slate, assigned by Grant and Higgins [7] to the Orca group and believed by them to be the upper

[2] Schrader, F. C., U. S. Geol. Surv., 20th Ann. Rep., pp. 404–417, 1900. Schrader, F. C., and Spencer, A. C., U. S. Geol. Surv. Spec. Pub., pp. 32–40, 1901. Grant, U. S., and Higgins, D. F., U. S. Geol. Surv. Bull. 443, 1910. Capps, S. R., and Johnson, B. L., U. S. Geol. Surv. Bull. 605, pp. 30–46, 1915. Johnson, B. L., U. S. Geol. Surv. Bull. 692, pp. 158–163, 1919.

[3] *Loc. cit.*, pp. 27–44.

[4] *Loc. cit.*, p. 33.

[5] *Idem*, p. 21.

[6] *Loc. cit.*, p. 44.

[7] *Loc. cit.*

part of the Orca. It is quite possible, however, that the slates and graywackes of Latouche Island are the equivalent of the "lower slates and graywackes" of Capps and Johnson and underlie instead of overlie the greenstone. Recently Mr. F. H. Moffit of the United States Geological Survey obtained some fossils from Montague Island, adjacent to Latouche, which Mr. Kirk thinks are cephalopods and of Paleozoic age. Mr. Moffit states "I would be more inclined, with my present knowledge, to include the Latouche rocks with those of Montague Island." [8]

Other rocks observed on Latouche Island are: a thin bed of limestone on the shaft level of the adjacent Reynolds-Alaska Copper Co. at Horseshoe Bay; conglomerates noted by Grant and Higgins [9] near the Beatson; gabbro described by the same authors [10] as being a dike 100 feet wide at the north end of the Island and basic dikes at the south end of the Island; mention has also been made of a "flinty rock" in the Bonanza Mine. In addition some green chloritic schists have been mapped in the underground workings and an unusual lamprophyre dike rock was discovered in the Beatson mine. The rocks with which the ore is associated are the green schist, the "flinty rock," and the graywacke and included slate. Descriptions of them follow.

Graywacke and Slate.—Graywacke and slate make up almost exclusively the bed rocks of Latouche Island. The two rocks are everywhere interbedded, but the relative proportions of each vary in different localities; graywacke predominates in the mine workings, but on the northwest side of the mine the series consists of slates with few beds of graywacke. The sedimentary series has been closely folded and in places overturned, so that steep dips prevail. In the vicinity of the mine they dip regularly westerly and strike northerly. The slates exhibit cleavage nearly parallel to the bedding, but the graywackes are massive.

A section across the bedding shows alternations from graywacke to slate and a casual glance gives the impression of absolutely parallel beds though with extreme variations in width in

[8] Personal letter dated March 6, 1924.

[9] *Loc. cit.*, p. 25.

[10] *Loc. cit.*, pp. 49 and 29.

the individual bands of either graywacke or slate. But detailed mapping in plan of several miles of underground workings shows that individual beds are not parallel and persistent; they are all flat lenses. Either thick or thin beds of slate or graywacke will taper and disappear. Occasionally a persistent bed is found.

The graywacke is dark gray to black in color with fine and medium grained texture. The individual grains comprising it are quite uniform in size, though occasional larger fragments of slate may be seen in it. Under the microscope it is seen to be made up of semi-angular to angular fragments of quartz, orthoclase, microcline, plagioclase, chlorite, mica, magnetite, limonite, calcite, zircon, and fragments of mud rocks. The sparse cement seems to consist of argillaceous and chloritic material. The rock approaches an arkose. The angular outlines of most of the grains and the small chemical decay of the feldspars and bits of ferromagnesian minerals show that the materials were derived largely by mechanical disintegration from a not far-distant land mass of some relief.

In places within the ore zone the graywacke is dense and some of it bears some resemblance to the "flinty rock" to be described later.

The slate is dense black or dark gray and under the microscope shows no distinguishing features. The individual beds range in thickness from a few inches to a few feet and all show a little cleavage.

Green Schist.—Conspicuous among the slates and graywackes exposed in the workings is a dark green to black, fine-grained rock that breaks with a hackley fracture and is somewhat schistose. It suggests at once the field name of chlorite schist. Wherever it occurs copper mineralization is more abundant and the bands of high grade ore consisting of blebs, bunches, and veinlets of almost pure chalcopyrite are invariably present in this rock. Its distribution is therefore of importance from the standpoint of localization of ore.

The rock is usually sheared and faults are always present where this rock occurs. Apparently it has yielded to rupturing more

readily than the other rocks. A grayish chloritic or "talcy" gouge is prominent along the faults and when water is present a slimy mud mass and cavey ground results. These features successfully disguised at first the identity of this rock that was the rich ore carrier, and unquestionably the heavy caving ground that gave difficulty in working the high grade stopes was determined by the distribution of this rock.

Its occurrence is confined to the west side of the ore body—the place of richest ore and the site of the important Beatson Fault. No doubt its presence influenced or even localized the location of the Beatson Fault. Likewise the Beatson orebody (Fig. 41) is aligned parallel to this rock and the Blackbird orebody to the north is also associated with it, but a discussion of its effect upon the distribution of ore is reserved for later pages.

It is an elongated body of rock and in general is parallel to the graywacke-slate bedding, but in detail its exact boundaries are obscure due largely to the mess produced in it by faulting, and to inaccessible workings. It narrows here and widens there—apparently transgresses graywacke-slate bedding at one place and is parallel to it in another. Certainly, however, it lacks the parallelism of the beds of graywacke and slate. How much of the variation in width is original—how much is due to faulting or squeezing from folding, is difficult to determine.

Microscopically, the rock is an enigma—a number of thin sections give no decisive knowledge of its origin. It is largely deep green-colored chlorite (probably prochlorite), so dense as to appear almost isotropic. Quartz veinlets cut it and isolated grains of quartz are scattered through it. Conspicuous are a number of minute areas of circular or roughly hexagonal outline that at first glance resemble spherulites. However, they are not. They are filled by a mineral, pale yellowish-white in color, that extinguishes like radiating quartz. I do not know what it is. Their centers frequently are seen to contain a minute speck of sulphide.

The rock is evidently an alteration product—but of what I do not know. Suspicion alone suggests a basic igneous rock, either

extrusive or intrusive, but facts are lacking and no conclusive opinions were deduced. It is not improbable that it is an altered basic rock that was extruded during the period of sedimentation. If so it has its counterpart in the interbedded greenstones that are found elsewhere in the Orca group.

"Flinty Rock."—This unusual rock has attracted the attention of all who have visited the property particularly because of its intimate association with the ore. It is gray to greenish in color, so dense that in places it resembles flint, so hard that it scratches steel, and it breaks with a smooth conchoidal fracture. It resembles no known rock and is obviously an alteration product. Inspection of hand specimens suggests that it might have been altered from slate, graywacke, tuff, limestone, or the green schist rocks. Grant and Higgins in discussing it[11] call it a "flinty aphantic rock" whose "origin is not clear but is probably a highly siliceous sediment" and that "in the field no banding or bedding was noted in this flinty rock, and its relation to the adjacent slates and graywackes was not clear."

Detailed geological mapping shows that its distribution does not conform with the bedding of the slates and graywackes; it transgresses and abuts the sedimentary beds. This is further proof of its derivation from some other rock and shows that it could not originally have been a bedded rock such as limestone or tuff. It must be an alteration product of some of the rocks that lie adjacent to it—either graywacke, slate, or green schist. Of these, the field evidence suggests that slate can be eliminated because of its practical absence from this part of the mine, the discrepancy in width between slate bands and the flinty rock, and the absence of slate in prolongation of the flinty rock along the strike. There is nothing to suggest, either from field or microscopic evidence, that the flinty rock may have been derived from small separate igneous intrusions.

A study of the underground detailed geological maps shows that the flinty rock is restricted chiefly to the vicinity of the Beatson fault. It thus coincides largely with the distribution of the

[11] *Loc. cit.*, pp. 30, 64.

green schist, the massive sulphide, the zone of best ore, and the area of the most abundant graywacke. This localized occurrence is marked on all the levels. A smaller amount of flinty rock occurs parallel to some other faults to the northeast of the Beatson fault on the Main Level. Its spacial connection with the best ore is brought out clearly by the maps. The field relations thus suggest that the flinty rock was formed at the place of the most intense mineralization and derived from either the green schist or graywacke. Of these two the green schist seems the more probable source because of its closer connection throughout the mine workings with the flinty rock. Although graywacke also occurs near the flinty rock, the latter is not found wherever there is graywacke, whereas the green schist and flinty rock are apparently always associated.

The microscope offers little conclusive evidence on the origin of the flinty rock. In thin sections it appears to be a dense felted mass consisting of minute quartz grains and green chloritic material. The green chloritic material is similar to that composing the green schist and suggests that the flinty rock was formed by silicification of the green schist. Some sections show what may be an intermediate step in which the chloritic material is dominant and the quartz appears to have spread through it at its expense.

Lamprophyre Dike.—A massive gray-black rock was found underground that resembles closely some varieties of graywacke, and was actually mistaken for graywacke, but suspicion was aroused that it might be an igneous rock. The microscope verified this and showed it to be an unusual dike rock, made up chiefly of brown mica and the alteration products of olivine. It is so altered that its identification is difficult. Its most conspicuous feature is large areas of talc of circular outline and a millimeter or so in diameter. One oval shaped area measured 5 x 7 mm. These are surrounded by shreds of brown mica both of which are set in a much altered fine grained groundmass. The talcy areas evidently were originally olivine. The brown mica is little altered and appears to be an original constituent. It is

wrapped around the olivine grains. One small area of feldspar remained. Magnetite is abundant and there is considerable carbonate. Apatite is also present as an accessory mineral. No pyroxene or amphibole could be recognized and it cannot be told if they were originally present. The rock is made up chiefly of olivine (which constitutes about 25 per cent. of the area of the section) and of biotite. It is, therefore, one of the lamprophyric dike rocks of unusual composition and suggests a basic differentiation product of a basic igneous rock.

The rock occurs as a narrow band in the ore zone and cuts the graywacke. Although considerably altered it has not undergone the shattering to which the surrounding rocks have been subjected. It is free from disseminated sulphides and its connection with the metallization is unknown. Its interest lies chiefly in its unusual composition and in its being an indication of igneous activity beneath this region—a feature of possible significance in connection with the origin of the ore deposit.

Attitude of the Rocks.—In the vicinity of the mine the rocks dip regularly to the west and strike slightly east of north. (Figs. 41, 42.) This strike is general throughout the island, though the dip varies from west to east due to close folding. The prevailing dip throughout the island, however, is westerly. Some light is thrown on the regional attitude of the formations by the finding underground in several places of flattened bits of slate in the bottom of beds of graywacke, showing that the hanging wall beds are younger than the underlying beds. As the prevailing dips are westerly this means that at the mine the younger beds lie to the west. This suggests that the graywackes and slates of Latouche Island are older than the greenstones which lie to the west and northwest on Elrington and Knight Islands, and that the sediments underlie rather than overlie the greenstones as suggested by Grant and Higgins.[12] This is one of the reasons for the statement made earlier in this paper that the Latouche slates and graywackes may be the equivalent of the "Lower slates and graywackes" of Capps and Johnson.[13] The possibility may also

[12] *Loc. cit.*
[13] *Loc. cit.*

be raised that the rocks of Latouche Island dip under and are older than those mapped to the westward by Grant and Higgins as belonging to the older Valdez group.

Faults.—Many faults have been mapped in the underground workings, some of which strike almost parallel to the bedding and a lesser but relatively more important number strike northeasterly. To this group belongs the Beatson fault, an important locus of mineralization. Within the mine it is marked by a zone of gouge, sheared and shattered rock, and cavey ground. The same zone of faulting extends northeasterly through the Chenega and Blackbird workings and has also been traced southwesterly through the old Reynolds-Alaska mine. Still farther to the southwest, the Seattle-Alaska prospect lies along what may prove to be a continuation of the same fault zone.[14] This fault forms the western boundary of the ore zone in the Beatson mine and all of the green schist and most of the flinty rock occur near it.

The stresses that gave rise to the Beatson fault also resulted in the formation of other smaller and parallel faults. A small amount of shearing of the graywackes and slate also took place.

ORE DEPOSITS.

General.—It has been pointed out by Johnson[15] that Prince William Sound contains two belts of mineralization, one of copper and one of gold. The Beatson mine lies in the former and is the most prominent example of the copper group—in fact it is at present the only producing copper mine in Prince William Sound. Both the copper deposits and the gold deposits are considered by Johnson[16] to belong to one metallogenetic epoch and to be parts of the same metal province.

The Beatson mine is of interest, therefore, in being economically the most important deposit of this Prince William Sound

[14] Mr. F. H. Moffit (personal communication) states that in 1923 he found a strong fault zone, apparently the continuation of the Beatson fault zone, to extend the full length of Latouche Island on the west side.

[15] Johnson, B. L., U. S. Geol. Surv. Bull. 662, 1917, p. 202, and Bull. 605, 1915, p. 50.

[16] *Loc. cit.*, pp. 74 and 86.

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copper mineralization, and the details of the deposit will now be considered in order that its relation to the other copper deposits may be known.

Character of Ore.—The ore as mined consists of sulphides intimately mingled with country rock in the proportion of about 12 per cent. sulphides to 88 per cent. gangue.[17] The sulphides occur as grains scattered through the gangue rock and as small veinlets of pure sulphides, or of quartz and sulphides. Vein quartz is negligible in amount and the gangue is made up almost entirely of graywacke, flinty rock, green schist, or slate. The sulphides consist chiefly of chalcopyrite, pyrrhotite, and pyrite,[18] and, as will be shown later, the minerals are all primary or hypogene.

In addition to the disseminated ore there is along the Beatson fault a body of massive sulphide consisting of pyrite and pyrrhotite with no appreciable copper content. (Fig. 41.) This body has been traced for about 800 feet and varies in width from 2 to 40 feet. It is left in the mine as waste. Also, there have been mined adjacent to the Beatson fault, small bodies of direct shipping ore containing from 5 to 10 per cent. copper. This higher grade ore consists of veinlets and blebs of chalcopyrite in green schist and is found only where green schist occurs.

The ore is sought for its copper content, but a small amount of silver is associated with the copper. An average smelter analysis of ore shows:

Cu	Ag	Au	Fe	SiO_2	Al_2O_3	CaO	MgO
2.2	0.35	Trace	12.4	61.0	6.28	1.42	7.21

A partial analysis of concentrates gives:

Cu	Ag	Fe	S	SiO_2	Al_2O_3	CaO
21.5	3.8	30.6	30.2	6.0	1.5	0.4

Shape and Size.—In a low grade disseminated deposit such as the Beatson orebody, its shape and size are determined by the

[17] A concentration ratio in milling of 11 to 1 with 86 per cent. recovery gives an idea of the proportion of sulphides to gangue.

[18] For other minerals see "Mineralogy."

lowest limit or metal content that make mining and milling operations profitable. Consequently the size of the deposit increases and the shape changes as lowered mining costs or increased milling efficiency enable lower grade ore to be mined. The outline of the workable ore is thus artificial. More highly metallized ground passes gradually into rock that contains less and less sulphides and the actual boundary between metallized and unmetallized rock is indefinite. Even the workings most remote from the workable ore usually contain traces of sulphides. On the west side of the ore body, however, this is not the case for the Beatson fault forms a sharp and relatively straight western limit to mineralization. The eastern boundary, however, resembles the irregularities of a submerged flat-lying coastal plain.

The ore body is elongated north and south, parallel to the Beatson Fault and roughly parallel to the strike of the bedding. The maximum horizontal length in this direction is about 1,000 feet. The maximum horizontal width normal to the Beatson fault is about 400 feet but the horizontal dimensions vary. As both ends taper, the metallized ground in plan resembles somewhat a huge fat lens, flat on one side and with protuberances on the other. Some areas of lightly metallized rock (or waste) occur within the lens. An outline of the ore body on the Main adit Level is fish-shaped as shown by Fig. 41. The shape at one cross-section is shown in Fig. 42.

The deposit dips fairly regularly to the west at an angle of 60 degrees and has been followed to date down the dip for a distance of about 500 feet. Diamond drilling shows that the ore continues below the 200 level, or the lowest working level, and a new lower level is being started.

Distribution of Ore.—In the Beatson mine all of the ore is confined to one ore body, but a horse of lower grade material (left as waste in mining) on the 200 level lies in the midst of the deposit, giving the appearance of an east and west ore body. The richest ore, as remarked previously, lies adjacent to the Beatson Fault.

Along the northward continuation of the Beatson zone of mineralization are the Chenega and the Blackbird deposits lying respectively 1,000 and 2,000 feet from the end of the Beatson deposit. These deposits are of the same general character as the Beatson, though smaller in size.

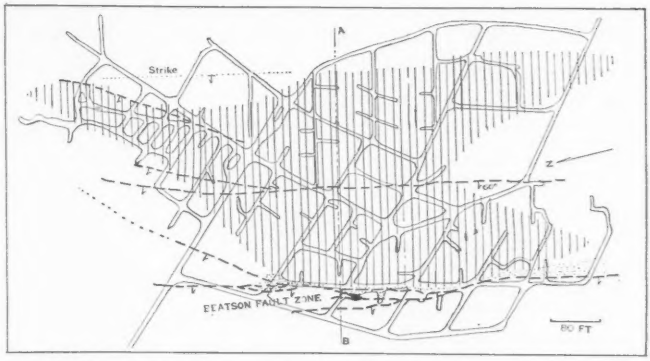

FIG. 41. Plan of Main Level, Beatson Mine, to show shape of ore body (shaded area), Beatson Fault zone, and massive sulphide (stippled).

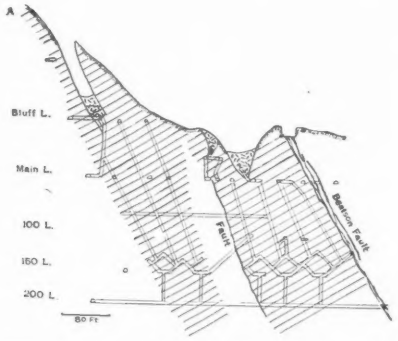

FIG. 42. Cross section of Beatson Mine along A–B of Fig. 41. Ore body is shaded area.

The southward projection of the Beatson zone intersects the Reynolds-Alaska mine (long since abandoned) at a distance of 2 miles from the southern end of the Beatson deposit.

Relation of Ore to Rocks.—The rocks of the mine in the order of their relative abundance are graywacke, flinty rock, slate, and green schist, and the amount of ore in these rocks is in direct proportion to their abundance. Contrary to the common impression, the ore suffers no diminution of value in the slates but a greater part of the ore is in graywacke simply because graywacke constitutes the bulk of the rock in the ore zone—a feature brought out clearly by the superposition of assay records on geological level maps.

The ore shows a distinct preference for the green schist and the flinty rock. The richest of the disseminated ore is in the green schist and all of the high grade shipping ore occurs in it. The ore in the flinty rock is in general higher grade than that in graywacke or slate.

It is thus evident that all of the rocks are ore containers, and that no one rock to the exclusion of the others has brought about ore deposition, although the green schist has exerted a greater influence on ore deposition than the rest. Thus the character of the rock has not been the dominating influence in localizing mineralization. It is likely that mineralization would have occurred at this place had even entirely different rocks occupied the place of the graywacke and green schist and flinty rock. Consequently there must be sought some cause for the localization of the metallization other than the character of the rocks.

There is no evident connection between the ore and the lamprophyric dike. It is not mineralized.

Relation to Fractures.—The alignment of the ore body corresponds with the alignment of the Beatson fault and with the sympathetic shearing and minor faulting that accompanied the Beatson movement. Both the shearing and the ore zone cut the steeply-dipping bedding at a slight angle, consequently the bedding by itself did not control the position of the ore. It is thus clear that the relation between the ore and the Beatson fault is a close one and that the Beatson fault zone has had a greater influence in localizing the ore than bedding planes or the character of the rock.

Type of Deposit.—The Beatson ore deposit is the result of the introduction of copper and iron sulphides, along with a little quartz and other minerals, into the fractured and slightly sheared country rock. Replacement was the chief process, as will be shown later, by which the introduced minerals occupied their present resting places, but some of the veinlets and threads of sulphides filled existing cracks. The deposit, therefore, belongs to the disseminated replacement type of intermediate depth, and exhibits certain resemblances to the disseminated lens-in-schist types, and to some of the disseminated "porphyry" copper deposits. No "porphyry," however, is present.

Relation of Ore to Surface.—The intersection of the ore body and the present surface is merely a coincidence of erosion. The deposit was formed long prior to the development of the present topography and at great depth beneath the then existing surface, and has been revealed only by the denudation of the overlying rocks. The relation to the surface, then, is purely accidental. Had erosion progressed less deep the ore body might never have been exposed or else the upward continuation of it would have formed the outcrop; had it been deeper, one of the lower levels might have formed the outcrop, and the part now being mined would have been disintegrated and transported elsewhere.

After the surface had been lowered to about its present position the ore deposit exerted a minor control over the details of the topography to be sculptured. The harder rocks of the ore zone resisted erosion more than the adjacent unsilicified rocks. In consequence a bluff marks the site of the ore deposit.

The last lowering of the surface was accomplished by glaciation. Glacial striæ may be observed on the top of the ore bluff and on the lower ground surrounding the bluff. The differential erosion by which the ore bluff remained as a surface projection was, therefore, done by ice. Since the time of glaciation atmospheric decay of the rocks has been negligible, else the glacial striæ would have been removed. A mantle of moss has formed an effective blanket to post-glacial erosion; small glacial

pebbles have been held by it on smooth and sloping glaciated surfaces.

Age of Mineralization.—The metallization, obviously, was later in age than all of the rocks of the ore zone, excepting possibly the lamprophyre dike. The graywacke and slate is considered by Grant and Higgins [19] to belong to the Orca group of Mesozoic age, probably Jurassic. Capps and Johnson indicate an uncertainty as to the age of the Valdez and Orca groups, but think that they belong to the Mesozoic,[20] while the suggestion of a Paleozoic age by Moffit has previously been indicated.

The Beatson mine itself offers no conclusive data as to the probable age of metallization.

MINERALOGY.

General.—The mineralogy of the Beatson deposit is relatively simple. Oxidation and enrichment are insignificant so that the introduced minerals of the ore are all primary or hypogene. The minerals that have been identified as having been deposited during the period of metallization are: chalcopyrite, pyrite, pyrrhotite, zincblende, chalmersite (cubanite), galena, quartz, siderite, ankerite,[20a] and possibly chlorite. Silver and gold are present in small quantities, but the forms in which they occur have not been recognized.

Ore Minerals.—The ore minerals constitute about 12 to 13 per cent. of the ore broken and of these chalcopyrite constitutes about half. Pyrrhotite and pyrite make up the other half. Zincblende, although widely distributed, occurs in very small amounts and chalmersite or cubanite is extremely rare. Only a few small specks of galena were seen.

Pyrite is subordinate to pyrrhotite and was the earliest of the sulphides to form. It occurs as isolated grains that may be shapeless or of cubical form. They are usually enclosed in chalcopyrite, pyrrhotite, or quartz.

[19] U. S. Grant and D. F. Higgins, U. S. Geol. Surv. Bull. 443, 1910, p. 33.

[20] S. R. Capps and B. L. Johnson, U. S. Geol. Surv. Bull. 605, 1915, pp. 34, 45, 82.

The remaining sulphides were essentially contemporaneous, although slight overlapping occurred. They occur singly or intermingled; veinlets and blebs of quartz and chalcopyrite, or quartz and pyrrhotite, or quartz alone, are as frequent as blebs or veinlets of mixed chalcopyrite, pyrrhotite, and quartz. Inclusions of chalcopyrite in pyrrhotite are almost as common as inclusions of pyrrhotite in chalcopyrite. In some cases pyrrhotite would appear to have been deposited earlier; in other cases chalcopyrite. On the whole they were deposited at about the same time with a slight tendency for pyrrhotite to be the earlier. There is an absence of veinlets of chalcopyrite cutting pyrrhotite and vice versa.

The zincblende occurs mostly as numerous small blebs of microscopic size within pyrrhotite and chalcopyrite. It usually contains minute specks of "pin-points" of chalcopyrite visible only with the higher powers of the microscope—an occurrence quite familiar to those who have studied mixed ores containing zincblende. One instance was noted of minute gash-like veinlets of chalcopyrite in the zincblende, so small that they could be seen only with magnifications in excess of 500 diameters. Instances were also noted of zincblende contained within blebs or veinlets of clear quartz and not associated with other sulphides. The outlines of the zincblende are smooth, sharp, and regular; no other minerals cut it nor is it cut by others; neither does it embay nor is it embayed by other sulphides. In general it is slightly earlier in age than the chalcopyrite and pyrrhotite though the "pin-point" chalcopyrite may have been earlier than the zincblende.

Chalmersite (*Cubanite*).—This mineral is of interest because it has not previously been recognized in the Beatson deposit. Merwin, Lombard, and Allen[21] of the Geophysical Laboratory

[20a] The ankerite was determined chemically and crystallographically for B. L. Johnson by Mr. Shaller of the U. S. Geological Survey. (Communication from Mr. L. H. Moffit.) Perhaps the siderite that I determined (unsatisfactorily) may also be ankerite.

[21] Cubanite: Identity with Chalmersite; Magnetic Properties, *Amer. Mineral.*, vol. 8, August, 1923, pp. 135–138.

of Washington, D. C., point out that it was found originally in Cuba and assigned the formula $CuFe_2S_3$, but that later several museum specimens labelled cubanite were found by microscopic examination to be inhomogeneous and the identity of the mineral cubanite was discredited. The same authors also show [22] that in 1902 the name chalmersite was proposed by Hussak for a mineral from Brazil similar to what cubanite was supposed to be. This name was then adopted by Murdock [23] and later Johnson discovered in eight localities in Prince William Sound, Alaska, a mineral which he compared with the Brazilian mineral and concluded to be chalmersite.[24] Still later chalmersite was identified and described by Schwartz from Fierro, New Mexico, and Parry Sound, Ontario.[25] Merwin, Lombard, and Allen have recently concluded [26] that chalmersite and cubanite are identical and suggest that cubanite being the older name should replace chalmersite.[27] The same authors point out that chalmersite (cubanite) is unique in having only one axis of high magnetic susceptibility.[28] The similarity between chalmersite and cubanite has also been pointed out, apparently independently, by Kalb and Bendig.[28a]

The Beatson chalmersite (cubanite) has similar properties to that described by Johnson from nearby Alaska occurrences. Mr. Johnson was kind enough to loan me his specimens so that the

[22] *Idem*, p. 136.

[23] "Microscopic Determination of Opaque Minerals," John Wiley & Sons, 1916, p. 72.

[24] Johnson, B. L., ECON. GEOL., vol. XII., 1917, pp. 519–525.

[25] ECON. GEOL., vol. XVIII., pp. 270–277.

[26] *Loc. cit.*

[27] Inasmuch as the specimens labelled cubanite in American museums have been shown by means of the reflecting microscope to be mixtures of known minerals, and as the cubanite specimens from Yale University, supposedly from the original locality are also mixtures, and as the original descriptions are somewhat vague, the writer feels that the evidence offered by Merwin, Lombard, and Allen is insufficient to discard the term chalmersite in place of cubanite, until the original material shall be examined microscopically. Therefore, the term *chalmersite* is in the meantime retained in this paper.

[28] *Loc. cit.*, p. 138.

[28a] Georg Kalb and M. Bendig, *Centralblatt für Miner. Geol. u. Paleon.*, Nov., 1923, p. 643.

Beatson chalmersite (cubanite) could be compared and checked with the other occurrences. Without such comparison the identity of the Beatson chalmersite (cubanite) would not have been conclusive because the few specks are microscopic in size and therefore difficult to test. The Beatson material was also checked with chalmersite from the type Brazilian locality in the Yale collections.

In the Beatson deposit the chalmersite (cubanite) is associated with the pyrrhotite and chalcopyrite. It occurs within both sulphides and is enclosed in quartz adjacent to the other sulphides. It shows no preference for chalcopyrite. The grains are shapeless and appear to have been formed simultaneously with the chalcopyrite and pyrrhotite.

The identification of chalmersite (cubanite) in the Beatson mine adds another locality to those found by Mr. Johnson and serves to link the Beatson deposit with other copper occurrences of this region. The mineral association at Latouche is also similar to that of the other localities where chalmersite (cubanite) has been noted. It is of interest in this connection that bornite is absent in the deposits that contain chalmersite (cubanite).

Gangue Minerals.—The only gangue minerals introduced with the metallization were quartz and a little siderite, and this lode quartz because of its clearness and form may be distinguished from the quartz originally present in the rocks. The quartz of the graywackes usually exhibits strain phenomena and contains many small inclusions.

The quartz was introduced slightly before and with the sulphides. Most of it is irregular in shape; some shows crystal outlines. It occurs as microscopic veinlets and irregular grains. Occasional macroscopic veinlets may be seen. The continuity of the quartz in the veinlets is in many cases broken by sulphides. Many veinlets and isolated grains of quartz are to be seen without any sulphides, but rarely does one see sulphides without accompanying quartz. Some of the quartz is intergrown with sulphides, but much of it shows embayments where sulphides

have eaten into it, or interruptions where sulphides have cut across the quartz grains. The greater part of the quartz has been formed by replacement of the country rock. The thin sections show that quartz preceded the sulphide deposition and continued to be deposited throughout the period of formation of the sulphides.

The chlorite of the green schists may possibly have been introduced in part at the time of metallization.

Mode of Entry.—The ore and gangue minerals occupied their present resting places both by replacement and by filling of existing cavities. The latter mode of entry, however, was relatively insignificant; the small fractures that existed were filled by sulphides and quartz and some pore spaces were occupied by grains of the same minerals.

All of the larger blebs and veinlets of sulphides and most of the smaller disseminated grains have replaced the country rock, or to a smaller extent the quartz introduced in the earliest stage of mineralization. The chlorite of the green schist was most readily replaced, for the sulphides occur not only in greater abundance but also in larger areas in this rock. But quartz grains, feldspar, clayey matter, and the cryptocrystalline quartz and chloritic material of the flinty rock all succumbed indiscriminately to the replacing sulphides. The massive band of pyrrhotite and pyrite is considered to have been formed by replacement, probably of the sheared green schist.

Oxidation and Enrichment.—The Beatson mine is another example of those sulphide ore bodies of glaciated regions in which oxidation and enrichment are negligible. One cannot say that oxidation and enrichment may never have taken place in this deposit, for the Kennecott mines of Alaska afford striking evidence of deep pre-glacial oxidation that escaped removal by glaciation and has been preserved by a fossil groundwater now in the form of ice.[29] If any pre-glacial superficial alteration existed in the Beatson mine it was entirely removed by ice erosion which left the zone of primary minerals outcropping on the surface. Since

[29] Bateman, Alan M., and McLaughlin, D. H., "Geology of the Ore Deposits of Kennecott, Alaska," ECON. GEOL., vol. XV., 1920, pp. 1–80.

the withdrawal of the ice from the site of the Beatson mine, oxidation has been negligible and some sulphides may be observed in the glacial grooves of the surface. Oxidation of sulphides in places has proceeded to a depth of a few inches and with respect to the part of the cropping removed prior to my study of the deposit, Lincoln states [30] that there was a thin gossan. Also the cropping of the massive sulphide along the Beatson fault yielded considerable limonite. Some of this remained *in situ* imparting to this portion of the outcrop the brown rusty appearance of the usual gossan. Much of the limonite, however, was transported in solution to the base of the bluff where it was deposited as a cement for talus material and in part as a thin layer of bog iron ore beneath the heavy mantle of moss. This limonite-cemented talus bears resemblances to other pyritic deposits where oxidation has resulted in some transportation of the iron as in Shasta County,[31] Huelua, Spain,[32] British Columbia,[33] and other localities.

Where the ore in the green schist has been oxidized, the rock is prominently stained beyond the limits of the cavities occupied by original sulphide. In the case of the flinty rock the cavities originally occupied by sulphides are slightly stained and the rock is not; the limonite was removed.

Native copper was observed in the form of a few small flakes in the oxidized green schist, but is of no economic importance. Lincoln reports [34] that aborigines pounded some native copper out of the rock with stone hammers.

Secondary sulphide deposition is negligible. In a few places some specimens were obtained from within a few inches of the surface that showed a thin coating of secondary covellite and sooty chalcocite. A little melaconite was observed and there are a few stains of copper carbonates.

[30] Lincoln, F. C., ECON. GEOL., vol. IV., 1909, p. 212.
[31] Cal. State Mining Bureau, Bull. 50, 1908, p. 65.
[32] Wetzig, B., *Zeit. Pract. Geol.*, vol. 14, 1906, pp. 173–186.
[33] Bateman, Alan M., Can. Geol. Surv. Rep. 1912, p. 186.
[34] *Loc. cit.*, p. 213.

RELATION TO OTHER PRINCE WILLIAM SOUND COPPER DEPOSITS.

The distribution and relations of the mineral deposits of Prince William Sound have been ably discussed by Johnson.[35] He points out that two groups may be distinguished—a gold group, and to the south of it, a copper group. The Beatson mine is included in the copper group. Johnson shows that the copper deposits, most of which I also have had an opportunity to study personally, contain similar minerals, are confined largely to greenstones, and are closely connected with faults and fissures. He also shows that the rare mineral chalmersite (cubanite) occurs in the deposits of Landlocked Bay and Knight Island. Its identification in the Beatson mine links this deposit with the others. Johnson also sets forth evidence to show that most of the copper deposits of this region have been formed by replacement of the enclosing rocks, and here lies another point of similarity between the Beatson deposit and the other copper deposits of the Sound. It is thus evident, without further discussion, that the Beatson mine is one unit, and the most important unit, of the Prince William Sound metal province as outlined by Johnson.

ORIGIN OF ORE DEPOSITS.

General.—If, as has been suggested on a previous page, the Beatson deposit is but one of a group of related ore deposits scattered about the Prince William Sound region, it must have been formed at the same time and by the same processes as the others. Consequently a knowledge of the origin of the others will throw light on the genesis of the Beatson deposit, and conversely inquiry into the Beatson deposit may help toward a better understanding of this province of mineralization as a whole.

The various observations and views of previous investigators in this region have been assembled in convenient abstract form by Johnson.[36] All of the investigators remark upon the association between the ores and the basic igneous rocks; some state that the source of the copper is obscure; others think that the ores

[35] "The Ellamar Dist.," S. R. Capps and B. L. Johnson, U. S. Geol. Surv. Bull. 605, 1915; *Mineral Resources*, by B. L. Johnson, pp. 50 et seq.

[36] *Loc. cit.*, pp. 52–61.

were derived either from the basic lava flows or from deep seated basic intrusives. Johnson presents a different view,[37] namely: that both the copper group and the gold group were formed from similar solutions and derived from a common source, *i.e.*, the Mesozoic granitic rocks. Later, however, Johnson concludes that the Jack Bay copper deposits were formed by solutions that appear to have been genetically related to basic intrusive rocks. However, he makes no mention of applying this change of view to the Prince William Sound copper belt.[38]

The Beatson mine of itself unfortunately offers too few conclusive data on this subject. What there is may now be discussed.

The Agency of Emplacement.—The foregoing descriptions of the deposit indicate that solutions most probably were the vehicle by means of which the metals were transported from their source of origin to their present resting place. The occurrence of the ore, or at least most of it, in sedimentary rocks and the absence of sizable igneous bodies preclude the possibility of an emplacement by magmatic segregation. Likewise the kinds of minerals, their associations, the rock alteration, and the nature of the deposit, eliminate a contact metamorphic or pneumatolitic process. Nor is a replacement deposit of this type susceptible of being interpreted as a magma injection. On the other hand, it is the type of deposit that customarily, and with reason, is considered to have been formed by solutions. Else how (in the absence of the evidence of gases) could the permeation of dense rocks and minerals, and the replacement of rock by ore, or ore mineral by ore mineral, have taken place? Solutions, therefore, were the agencies of transportation of the metals.

Character of Solutions.—The character of the solutions that produce ore deposits can be arrived at only by inference. Frequently the bases of sound inference are scanty or lacking, and in this respect the Beatson deposit is no exception. From the physical standpoint the metallizing solutions that produced the

[37] *Loc cit.*, p. 75 et seq.

[38] Johnson, B. L., "Mineral Resources of Jack Bay and Vicinity," U. S. Geol. Surv. Bull. 692–C, p. 166, 1919.

Beatson deposit must have been attenuated—at least thin enough to find passage through microscopic cracks and to penetrate dense and relatively impervious rocks. Their temperature and pressure must have been moderately high for the minerals and their associations are characteristic of primary deep-seated deposits of the intermediate vein zone of Lindgren.[39]

As to their chemical nature it is definitely known that the solutions were able to transport, and did bring in, copper, iron, silver, gold, zinc, lead sulphur, carbon dioxide, and silica. It is also definitely known that they were able to take parts of the different rocks into solution. Further than this must be conjecture. It is commonly considered that such substances as are mentioned above are carried by alkaline carbonate solutions [40] and the Beatson mine offers no new evidence on this subject.

Source of Solutions.—The accumulation of evidence of the connections between ores and igneous rocks causes one first to look to intrusives as the possible source of an ore deposit. He who would seek elsewhere for the source of mineralizing solutions finds that the burden of proof rests on him. In the case of the Beatson deposit conclusive proof of a magmatic or meteoric origin of the solutions is lacking. Certain features, however, suggest that magmatic origin is the more probable.

What is definitely known is that the ore is later than the enclosing sedimentary rocks, and further that the sulphides were deposited after the mud rocks had been metamorphosed to slates and had been sheared. Since the greenstones, or altered lava flows, were supposedly contemporaneous with the sediments, it follows that the metallization was separated from the lava flows by a time interval at least long enough for the intercalated mud rocks to have been changed to slate. Thus a close connection between the lava flows and the ore seems improbable. It should be mentioned, however, that Brooks [41] states that a genetic relation

[39] "Mineral Deposits," McGraw-Hill & Co., 1919, pp. 546–650.

[40] Lindgren, *loc. cit.*, p. 562. Allen, E. T., and Crenshaw, J. L., *Am. Jour. Sci.*, vol. 34, 1912, p. 358.

[41] "Future of Alaska Mining, Alfred H. Brooks and G. C. Martin, U. S. Geol. Surv. Bull. 714 A, 1921, p. 20.

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between the greenstones and ore seems probable. Further evidence of such a time interval is to be found in the occupation by the ores of shear zones in the greenstones of the Ellamar district, as pointed out by Johnson,[42] and this would also be the case in the Beatson mine, if the green schist be a lava or greenstone intrusive derivative.

It is also known that a narrow lamprophyre dike was intruded into the ore zone at a period later than the metamorphism of the enclosing sediments. This indicates that at one time magma lay somewhere beneath the region of the present ore deposit. Since ore and dike both came in after the metamorphism of the sediments, it is at least suggestive that both may have come from a common source—an underlying magma. If the solutions be magmatic, as most metallizing solutions are, here, then, is a possible adjacent igneous source for them. A further suggestion of magmatic origin for the Beatson solutions is that waters which have produced similar results elsewhere invariably are considered or proved to have been derived from magmas. This conclusion has been reached by Johnson for the nearby deposits of the Ellamar district.[43]

It seems more plausible and probable to assume that the high temperature solutions, such as the Beatson ones must have been, were magmatic waters, and such is the writer's conclusion.

Abundant evidence of intrusive rocks from which the solutions may have issued is not to be seen at the Beatson mine. But Grant and Higgins have shown that gabbro occurs at the north end of Latouche Island [44] and the lamprophyre dike has already been mentioned as evidence of an underlying intrusive.

As to the kind of magma from which the metallizing solutions were derived, there is again little evidence. The gabbro at the north end of the Island may represent either an offshoot from a basic reservoir beneath, or a basic differentiate from a magma of intermediate or acidic composition. If the latter were the case, one should expect acid complementary intrusives, but none have

[42] *Loc. cit.*

[43] *Loc. cit.*, p. 80.

[44] Grant, U. S., and Higgins, D. F., U. S. Geol. Surv. Bull., 19, p.

even been seen. The lamprophyre dike suggests a differentiate from a basic magma. Thus there is no conclusive proof as to whether the source rock was granitic or basic, though the inconclusive evidence for the Beatson deposit favors a basic parent magma.

Grant and Higgins [45] believe that the copper ores were probably formed in connection with the intrusion of basic igneous rocks, though they fail to show any direct connection between such rocks and the deposits.

Johnson, as already mentioned, thinks that both the gold and copper ores were formed as an after effect of granitic intrusions. It may be pointed out, however, that there are essential differences in the gold deposits as described by him [46] as associated with the granites, and the copper deposits further south. Also any direct genetic connection between the gold ores and granite is far from being established, and the relation of the copper ores to the granites is based largely on inference. No granitic rocks are known near the localities of the copper deposits, and no workable copper deposits are known near the granitic intrusives. On the other hand, as has already been mentioned, basic intrusives do occur in the vicinity of the Beatson copper deposit and other basic intrusives have been described by Grant and Higgins [47] near other Prince William Sound copper deposits. It would appear, therefore, that no connection of the Prince William Sound copper ores either with granitic or basic rocks is established, but that the scanty evidence that is available favors somewhat derivation from a magma that yielded basic rocks.[48]

Still another feature adds slightly to the possibility of a connection with basic rocks: The Beatson deposit is linked with the adjacent Knight Island copper deposits by the rare mineral chalmersite (cubanite). The Knight Island deposits are reputed to carry a small amount of nickel as has also the Beatson deposit.[49]

[45] U. S. Grant and D. F. Higgins, U. S. Geol. Surv. Bull. 443, 1910, p. 58.

[46] *Loc. cit.*

[47] *Loc. cit.*, pp. 49–57.

[48] Note also Johnson's conclusion of derivation from basic intrusives for the Jack Bay copper deposits mentioned at the beginning of this chapter.

[49] Lincoln, F. C., *loc. cit.*; p. 209; U. S. Geol. Surv. Bull. 692, p. 145, 1919.

Nickel is a metal invariably associated with basic igneous rocks, or at least with magmas that yielded large basic differentiates. Further to the east of Prince William Sound, on Yakobi and Baranoff Islands also, are several nickel deposits (as yet of no economic importance), associated with basic rocks. Specimens of ores from these occurrences were examined under the microscope and found to contain pyrrhotite, chalcopyrite, and small amounts of pentlandite and polydymite, and hand specimens resemble those from Sudbury, Nickel Gap Mine, Pennsylvania, and the Norwegian occurrences.

There is nothing to suggest that the metals in the deposits were not derived from the same source as the magmatic waters.

Cause of Localization.—The Beatson fault zone, with its accompanying shearing, unquestionably was the chief cause of localization of the Beatson ore body as well as the adjacent Chenega and Blackbird deposits. The green schist was a secondary locus; it helped localize the fault itself and acted as a more congenial host rock for ore than the other rocks. But the fault zone was the channelway along the metallizing solutions were directed upward until they reached the place where deposition could occur. And in their upward journey the solutions were confined to the shattered footwall side of the westward-dipping fault, nor did they, at least in the depth exposed to view, break through the impervious gouge of the fault. The mineralization is all on the footwall side. Consequently the sloping fault acting as a dam concentrated the upward currents toward the east, as a roof directs to the eave troughs all of the rain water that falls on its surface. By this may be explained the concentration of rich ore and the bands of solid sulphide on the immediate footwall of the fault. Likewise it accounts for the more diffused mineralization on the lowest level, like the scattered drops of rain just before they touch the roof.

Depth of Deposition.—The minerals of the deposit are those considered to have been formed at considerable depth beneath the surface and at moderately high temperature.[51] At just what

[51] W. Lindgren, "Mineral Deposits," McGraw Hill Co., 1919.

depth cannot be told, but it must have been several thousand feet. The present vertical range of metallization extends from 150 feet below sea level in the Beatson mine to 1,200 feet above sea level on a nearby claim. Within this small range no change in the character of the ore can be detected.

As to the distance the solutions travelled before reaching their site of deposition, nothing can be told. Presumably it was considerable.

As to why the metallic load of the solutions was arrested in its upward journey by deposition at the place of the present deposit, is not revealed by the geologic record. Neither the top nor the bottom limits of metallization are known. Geologists usually consider, when certain rocks like limestone obviously have not produced precipitation, that the depth of deposition is controlled by temperature and pressure, *i.e.*, that the solutions in their upward journey through cool rocks undergo a lowering of temperature and pressure until a point is reached at which the mineral matter is no longer soluble, and then deposition takes place.

Possibly the place of deposition may in part be controlled by the ratio of concentration of certain ions in the solution. It has been pointed out before [52] that the relative concentration of iron and copper in a solution will determine whether deposition takes place of copper-iron sulphides or copper sulphides. With high relative concentration of ferrous iron, deposition of copper-iron sulphides (chalcopyrite) will occur, and if the concentration of ferrous iron remains high no copper sulphide will form. With high ferrous iron concentration, then, chalcopyrite [53] would be the expected copper mineral. The abundant chlorite does suggest high ferrous iron content. It is possible that deposition of either copper-iron sulphides or iron sulphides cannot take place until the solutions attain a given range of concentration of iron ions—a feature that may be dependent upon the distance of travel of metallizing solutions through rocks and the reaction that takes

[52] Bateman, Alan M., "Primary Chalcocite," ECON. GEOL., vol. 18, 1923, p. 158.

[53] Known now to be composed of the cupric and ferrous sulphide molecules, see Bateman, Alan M., *idem.*, p. 153.

place between rocks and solutions. It would seem as though temperature would also enter in.

Manner of Deposition.—When the conditions within the solutions, whatever they were, were ripe for deposition to take place, the ore minerals were deposited by replacement, and to a minor extent by filling small cavities. The rock material was removed and an equal volume of ore and gangue minerals left in its place. Some overlapping of deposition took place in which later sulphides corroded or replaced earlier deposited minerals.

SUMMARY.

1. The Beatson mine of the Kennecott Copper Corporation at Latouche Island is, next to the Kennecott mines, the largest copper mine in Alaska and produces more tonnage than any other individual copper mine in the Territory. It is economically the most important member of the copper province of Prince William Sound. The deposit is representative of a perplexing type of irregular lens-like bodies of copper and iron sulphide ores in schists, and has many analogies elsewhere.

2. The associated rocks consist of a series of old graywackes and slates with which occur green schist, a peculiar flinty rock, and a lamprophyre dike unusual in composition.

3. The deposit is an irregularly shaped elongated body aligned along a prominent fault zone that acted as the chief locus of mineralization. A green schist is a secondary locus.

4. The ore consists of chalcopyrite, pyrrhotite, and pyrite with minor amounts of zincblende, galena, and chalmersite (cubanite). It occurs as scattered grains, blebs and veinlets. There are occasional bodies of higher grade copper ore, and large masses of solid and barren iron sulphides.

5. The ore gained entry to the rock chiefly through replacement; cavity filling is insignificant.

6. Glacial erosion planed off the upper part of the deposit. Since that period, due to the short length of time and to the coldness of surface waters, oxidation and enrichment have been negligible.

7. The deposit is believed to have been formed at considerable depth by attenuated magmatic waters, alkaline in character, under conditions of moderately high temperature and pressure.

8. The solutions and metals may have been derived from the magmas that yielded either the granitic or basic intrusives of the region. The evidence is inconclusive but favors the latter.

9. A factor in the deposition may have been the relative concentration of ferrous ions in the solution.

I wish to acknowledge with grateful appreciation the helpful discussions with my colleagues Professor Adolph Knopf and Professor Charles H. Warren of the Department of Geology, Professor Harry W. Foote of the Department of Chemistry, and Mr. F. H. Moffit of the U. S. Geological Survey.

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A MAGMATIC SULPHIDE ORE FROM CHICAGOF ISLAND, ALASKA.[1]

PAUL F. KERR.

INTRODUCTION.

SEVERAL occurrences of nickel ores have been observed along the west coast of the Chicagof Island, Alaska, on the side toward the Pacific Ocean, between Portlock Harbor and Lisianski Strait. Little development work has been done on the outcrops and knowledge concerning the extent of metallization is limited. Specimens have been obtained from the workings, however, that show mineral relations which are sufficiently interesting to warrant a somewhat detailed description.

The general geology of the west coast of the island has been described by R. M. Overbeck.[2] He discusses the nickeliferous deposits and states that they form irregular iron stained outcrops occurring near the sea shore. The outcrops are contained in an igneous intrusion and are adjacent to a contact with quartz-mica schist. Overbeck believes a definite relation to exist between the ore deposition and the contact of the schist with the intrusion, since the nickel minerals are found either near or in the vicinity of the contact. The country rock is diorite and hornblende gabbro. He further states that the contact between the barren rock and the ore in a drift connected with a small prospect shaft is irregular and the transition from one to the other is rapid. He also calls attention to the marked resemblance between the Alaska nickel deposits and the deposits of the Sudbury district in Canada. No endeavor was made in his description, however, to attempt a

[1] It is a pleasure to thank Mr. F. L. Hess, who has kindly furnished a suite of ore samples and Professors A. F. Rogers and C. F. Tolman, of Stanford University, who have courteously offered suggestions in the study of the suite.

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[2] "Mineral Resources of Alaska," U. S. G. S. Bull. 692, 1917, pp. 125–133.

classification of the orebody. It is the object of the present paper to describe the ore in detail and present such conclusions as it may seem justifiable to deduce from a detailed study of the suite of specimens at hand.

DESCRIPTION OF THE ORE.

The ore is massive with pyrrhotite and chalcopyrite predominating. Patches and specks of dark colored silicates are disseminated through the sulphides. Small crystals of pyroxene are abundant and represent the only silicate that can be identified without microscopic aid.

Polished surfaces and thin sections show the predominance of pyrrhotite and chalcopyrite, indicate the presence of pentlandite, and emphasize the fact that there is an abundance of pyroxene, plagioclase, and amphibole accompanying the sulphides. The silicates are in a large part residuals of a gabbro and in some places the sections show remarkably fresh and unaltered portions of an igneous rock. It seems noteworthy that a rock containing such a quantity of ore minerals should itself have so little alteration.

THE GABBRO.

Fig. 43, A and B show sections of the gabbro. In the two figures the minerals which are constituents of the original igneous rock are pyroxene, labradorite, hornblende and a colorless amphibole which is probably edenite. The pyroxene occurs in euhedral crystals that are surrounded in some cases by ore and in others by labradorite. The hornblende and edenite which occurs on the edges of areas of the other amphibole are both formed at the expense of the pyroxene and may be seen cutting across crystals of the latter. The pyroxene and hornblende show signs of replacement by the ore minerals. The tremolite shown in Fig. 43 A is produced by a subsequent alteration to be discussed later.

Labradorite.—The plagioclase is labradorite. It has a maximum extinction angle of 32½° on twin sections with equal illumination parallel to the vibration planes of the two nicols and shows both pericline and albite twinning.

The labradorite shows reaction rims (probably composed of edenite) along the boundaries with the sulphide ore minerals that present a "fused" appearance. It does not, however, show evidence either of replacement or alteration by the sulphides.

Pyroxene.—The pyroxene is an isomorphous mixture of diop-

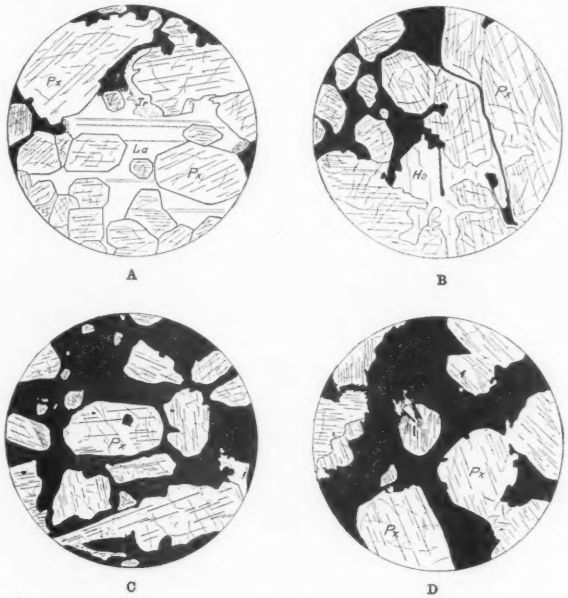

FIG. 43.

A. Textural relations of original igneous rock. Pyroxene, labradorite, tremolite and ore (black). Labradorite shows reaction rims along boundary with ore. The tremolite is due to a later alteration. Thin section drawing, × 25.

B. Euhedral pyroxene surrounded by ore. Hornblende replacing pyroxene and in turn cut by ore. Thin section drawing, × 25.

C. "Skeleton-like" remains of pyroxene in ore. Thin section drawing, × 25.

D. Tremolite on the border of an isolated pyroxene crystal and protruding into the ore. Thin section drawing, × 30.

side and hedenbergite. The indices of refraction are n_α 1.663 $\pm$ .002, n_β 1.678 $\pm$ .002 and n_γ 1.683 $\pm$ .002; the maximum extinction angle is 42°; the double refraction is about .020 and the axial angle is large.

The habit of the pyroxene is prismatic, elongated in the direction of the c-axis and with front and side pinacoidal faces more prominently developed than the prism form. A very fine-lined schiller structure accompanies the cleavage at a maximum extinction angle of 6° on either side of those crystals having parallel extinction.

The mineral has been fractured in places. Elongated sections have in some cases been broken into several portions, each making a different angle with what was originally a straight line. Isolated crystals of the pyroxene entirely surrounded by ore are common and it is also noticeable that the ore minerals have "eaten" into some separated crystals giving them a skeleton-like outline. These crystals although largely replaced by ore are often otherwise unaltered.

Hornblende.—Subsequent to the formation of the pyroxene and laboradorite there was an extensive alteration of the former to brown hornblende and a colorless amphibole corresponding to edenite occurring on the borders of the hornblende. The axial colors of the hornblende are α, brown; β, light brown; γ, colorless and in optical orientation with relation the crystallographic axes of reference, $a = \alpha$ (nearly), $b = \beta$, and c is 22° from γ. Characteristic cleavage is developed parallel to (110), the double refraction is about 0.018 and the mineral is optically negative. The pleochroism is pronounced and in absorption $\gamma > \beta > \alpha$.

Hornblende is shown in Fig. 43 B cutting across the pyroxene and replacing it. The amphibole is in turn replaced and cut by later ore minerals. Some areas of pyroxene present a "freckled" appearance due to the contrast of color between rounded alteration patches of brown hornblende and the clear areas of the surrounding pyroxene.

THE SULPHIDE MINERALS AND THEIR RELATIONS.

The sulphide minerals are pyrrhotite, pentlandite and chalcopyrite. Pyrrhotite occurs in anhedral crystals that are in some cases surrounded by chalcopyrite. The chalcopyrite is massive and irregular in outline. Pentlandite is present in two generations readily distinguished from each other by their form. The first generation appears on the borders of areas of pyrrhotite along some of the boundaries with chalcopyrite and can be distinguished on polished surfaces with the unaided eye. Under the microscope it shows octahedral parting and gives the micro-chemical dimethylglyoxime test for nickel.[2] The second generation is not visible without high magnification and consists of small disseminated patches and veinlets in the pyrrhotite and chalcopyrite.

The determination of the order of introduction of the pyrrhotite and chalcopyrite is not conclusively definite but a few veinlets of chalcopyrite in pyrrhotite and some residuals of the latter in chalcopyrite indicate the priority of the pyrrhotite. The first generation of pentlandite occurs in the pyrrhotite and is separated from areas of chalcopyrite. The second generation, however, is disseminated through the chalcopyrite in small veinlets. The veinlets are not continuous with the larger areas of the first generation and together with the specks are visible only under high magnifications.

The sulphide minerals appear in all cases to have been introduced later than the labradorite, pyroxene and hornblende. The criteria for this view are the "eating" of crystals of pyroxene by pyrrhotite and chalcopyrite showing skeleton-like outlines that are indicative of direct replacement of the silicate by the ore; embayments of ore in euhedral crystals in which replacement has taken place; the penetration of ore within pyroxene crystals along planes of parting; the fracturing of crystals and subsequent filling of the interstices between the portions broken apart by the ore minerals. These observations aside from the fracturing apply to

[2] A drop of diluted aqua regia and citric acid solution of the ore brought in contact with a drop of alkaline solution of dimethylglyoxime in alcohol will produce a scarlet precipitate that may be readily observed under the microscope.

both the pyroxene and hornblende. Crystals of hornblende which have been cut by veinlets of chalcopyrite and pyrrhotite appear in thin sections.

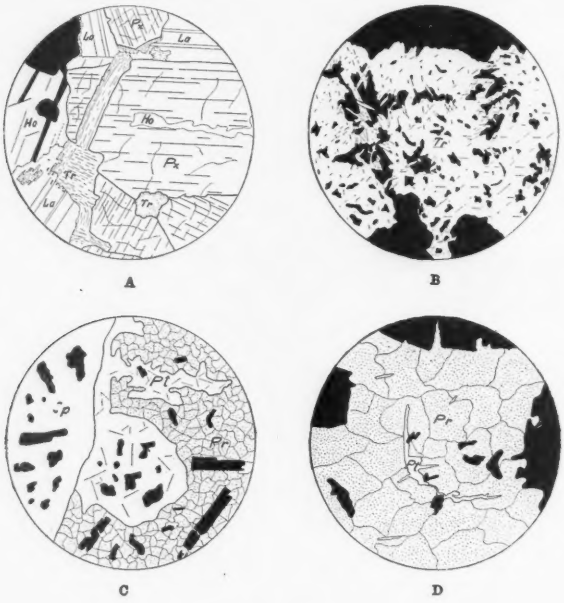

FIG. 44.

A. Pyroxene replaced by tremolite; hornblende cut and replaced by ore; reaction rim between labradorite and ore. Thin section drawing, × 25.

B. Needles of tremolite protruding into chalcopyrite. Chalcopyrite is shown black and tremolite white to bring out contrast. Polished surface drawing, × 275.

C. Typical surface of ore with pyrrhotite containing pentlandite (first generation) along the boundry with chalcopyrite. The silicates appear black. Drawing of polished surface, × 12.

D. Pentlandite (second generation) surrounded by pyrrhotite. Pyrrhotite is indicated by anhedral crystals. The silicate minerals appear black. Drawing of polished surface, × 250.

TREMOLITIZATION.

Fig. 44 B represents an area of tremolite and chalcopyrite under high magnification. The tremolite shows small "needle-like" crystals that penetrate into the chalcopyrite. Rhombic sections surrounded by chalcopyrite are visible in a number of places. Under lower magnifications occasional veinlets containing aggregations of tremolite crystals cut across chalcopyrite. Fig. 43 D shows tremolite on the edge of a pyroxene crystal apparently replacing the surrounding ore mineral. Such evidence indicates the replacement of chalcopyrite by tremolite as a late stage of alteration following the introduction of the sulphides.

The tremolite is later than the pyroxene, labradorite and hornblende. It forms in needle-like aggregates on the borders of pyroxene and hornblende crystals and in some places cuts across the elongated pyroxenes. Fig. 44 A shows tremolite "needles" formed on the end of pyroxene crystals and cutting across them. The penetration of labradorite by tremolite is a minor feature. Tremolite is evidently introduced as a later stage probably of hydrothermal alteration, following the magmatic changes.

ORDER OF MINERALIZATION.

The order of mineralization may be summarized from the above as follows: 1. Labradorite; 2. Pyroxene; 3. Hornblende (Edenite); 4. Pyrrhotite; 5. Pentlandite, 1st generation; 6. Chalcopyrite; 7. Pentlandite, 2d generation; 8. Tremolite.

CONCLUSION.

The history of the ore may be outlined in the following stages: (1) the crystallization of the original igneous rock; (2) the alteration of the pyroxene to hornblende; (3) introduction of the ore minerals; (4) tremolitization. The formation of the ore occurred at a late magmatic stage in close connection with and closely following the crystallization of the rock. This is brought out by the observation of abundant euhedral pyroxene crystals entirely surrounded by ore, the fresh appearance of the original

rock and the clean cut character of replacement in the pyroxene and hornblende. Hence the ore minerals and the relations which they exhibit toward each other are of the distinctly magmatic type.

The alteration of the gabbro by hornblende is probably a late magmatic stage and according to the views of Tolman and Rogers[3] is a common phenomenon observed in magmatic sulphide ores. They also state that a subsequent hydrothermal alteration of the ore minerals to tremolite is not uncommon in such ores. Thus it seems reasonable to conclude that the ore is " magmatic " and the tremolitization is a later and probably hydrothermal alteration.

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[3] Tolman, C. F., Jr., and Rogers, A. F., " A Study of the Magmatic Sulfid Ores," Stanford University Press, 1916.

HIGH TEMPERATURE MANGANESE VEINS OF THE CUYUNA RANGE.[1]

GEORGE A. THIEL.

INTRODUCTION.

In a previous paper [2] the writer has referred to various types of veins cutting the cherty carbonate slates of the Deerwood formation [3] and noted the presence of minerals that are characteristic of high temperature deposits. A more comprehensive study of the veins shows that at least a part of the manganese of the manganiferous ores of the Cuyuna Range was introduced into the sediments after the major deformation and metamorphism had been completed. This in no way modifies the conclusion that much of the manganese owes its origin to an earlier bedded carbonate precipitate. The latter is typically of sedimentary origin, whereas the veins fill fissures and fractures in the sediments.

The writer wishes to acknowledge the helpful suggestions offered by Dr. F. F. Grout in making this study.

Distribution of Manganese.—The manganiferous iron ore on the Cuyuna Range is located in a belt along the north margin of the north range, from the Sagamore Pit southwest of Riverton to the Northland mine north of Rabbit Lake. The highest grade manganese ore has been taken from the group of mines north of the Mahnomen pit, in the region of Mahnomen Lake. At the present time both the Sagamore and the Milford mines are shipping iron ore that carries from 10 to 12 per cent. of manganese.

In none of the mines in the belt of manganiferous ore is manganese-bearing carbonate found in the ore-body, with the excep-

[1] Published by permission of the Director of the Minn. Geol. Survey.

[2] Thiel, Geo. A., "The Manganese Minerals, their Identification and Paragenesis," Econ. Geol., Vol. 19, p. 107, 1924.

[3] Harder, E. C., and Johnston, A. W., "The Geology of East-Central Minnesota," Minn. Geol. Survey Bull. 15, 1918.

tion of small masses of pink carbonate deposited from meteoric solutions as linings in cavities and fractures. Where the ore has been concentrated, the carbonates have been oxidized and the silicates of the veins are decomposed. Thus the veins break up and lose their identity as structures in the ore. In the wall-rock, however, all stages from veins partially replaced by manganese and iron oxides to those with fresh, unaltered, high temperature constituents are readily located.

The area containing veins includes the entire region that produces manganiferous ore. At the Sagamore pit on the southwest extremity of this belt, veins are found cutting the slates in the pump shaft on the southeast wall of the pit. At the group of mines in the region of Mahnomen lake, including the Cuyuna-Mille Lac, the Mangan group and the Merritt mines, many veins, some of which are of a coarse pegmatitic character, are encountered. Further towards the northeast at the Milford Mine and at the Northland mine to the north of Rabbit Lake, fresh unaltered veins from less than an inch to over a foot in width, cut the metamorphosed slates.

Composition of the Veins.—The following types of veins have been identified:

1. Quartz-microcline-epidote and manganiferous carbonate.
2. Quartz-albite-specularite-apatite and manganiferous carbonate.
3. Quartz-adularia-epidote-diopside and manganiferous carbonate.
4. Quartz-biotite-specularite-apatite veins.
5. Quartz-carbonate-stilpnomelane veins.

The carbonate in the veins is clearly a primary mineral. Some of the grains are slightly corroded and others are entirely surrounded by quartz and feldspar. Much of the feldspar is altered to kaolinite, but numerous grains have distinct twinning bands. Some albite is in very irregular grains with sharp angular outlines. The twinning bands are extremely irregular. Some pinch out rather uniformly across the mineral grain giving the appearance of rows of interlocking wedges; others have frayed and

irregular bands that end abruptly, and still others show small but sharp angular offsets that might imply displacement. Diller [4] states that this phenomena indicates the rock has been subjected to pressure since it solidified. Evidence of wavy extinction is, however, lacking.

Further evidence in favor of the primary origin of the carbonate is the fact that the epidote also crystallized later than the carbonate minerals. Many large grains surround areas of carbonate, and numerous stringers of epidote cut across grains that possess characteristic carbonate cleavage and twinning. The epidote is brownish-green in color and is moderately pleochroic. It is found in clusters of large grains that have a tendency to be arranged in groups near the walls of the vein.

Specularite is not abundant in the veins that carry carbonate, but its presence shows the relation of the veins of this type to the quartz specularite veins that are especially abundant at the Mangan and Merritt mines.

The quartz-biotite[5]-apatite veins carry only small amounts of carbonate. The minerals are in relatively coarse grains, arranged so as to produce symmetrical banding. Most of the biotite is confined to the outer margins and is followed by a band of biotite, apatite and quartz. The central portion of the vein is mostly pure quartz. Locally the veins show evidence of a later period of quartz deposition, as fractures cutting all of the minerals are filled with fine-grained quartz of a later generation. At the Milford mine pyrite is extensively associated with the later quartz veinlets.

The carbonate veins with quartz, adularia, epidote and diopside show an unusual mineral combination. The carbonate occurs along the walls, with quartz and adularia filling the center of the veins. The carbonate is in sharp contact with the ferruginous slate but, along the inner margin of the band, the crystals project irregularly between the quartz and feldspar. Many of the carbonate crystals are corroded, but some show euhedral outlines.

[4] Diller, J. S., U. S. G. S. Bull. 150.

[5] Analyses may show this mineral to be stilpnomelane.

The epidote is mostly in the carbonate bands and occurs in elongated grains many of which possess euhedral outlines. Some of the larger crystals project as tooth-like structures into the quartz-feldspar areas. Apatite inclusions are present but not abundant. Associated with the epidote are irregular grains of diopside.

The adularia is in the form of rhombic euhedral crystals surrounded by quartz. The crystals show a tendency to be grouped or segregated in the quartz, indicating that their crystallization was complete prior to the solidification of the quartz. Numerous adularia crystals have a reticulate network of fractures in which secondary minerals are evident.

The presence of adularia, pyroxene and epidote in the same vein is quite contrary to the generally accepted views of mineral associations. Adularia is present in numerous districts in the Cordilleran region as part of the filling in veins or as a metasomatic product in the country rock, but it is invariably associated with minerals that are characteristic of the shallow zone. "High temperature minerals such as augite, amphibole, olivine, tourmaline, topaz, garnet, magnetite, ilmenite and chromite are conspicuously absent" (Lindgren).

In many metalliferous districts in the west, adularia occurs in veins that originally possessed a calcite gangue, that was later replaced by an intimate intergrowth of quartz and adularia. In the Cuyuna veins, however, the relation of quartz-adularia to the carbonate precludes such an interpretation, as numerous euhedral crystals of carbonate project into the quartz-adularia area. Furthermore, no stringers of the latter are seen cutting the carbonates. The structure of the vein, therefore, makes untenable any explanation of the association that calls for a later introduction of shallow zone minerals.

The quartz-carbonate-stilpnomelane [6] veins are abundant in the carbonate horizons. The stilpnomelane is present as a velvety coating along the fractures or as masses of foliated plates between the mineral grains. It is dark green in color and appears

[6] The writer is indebted to Dr. F. F. Grout for the identification of this mineral.

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similar to green mica. No characteristic high temperature minerals were found associated with it and consequently its origin is uncertain.

Manganese Content of the Carbonate Minerals.—Samples of the veins were crushed and the carbonate minerals isolated for analysis. Some of the pink carbonate effervesces slightly with cold acid and is undoubtedly a manganiferous calcite. Other samples with a darker bronze color give a strong test for iron.

Quantitative determinations of the manganese content in samples from different veins show that it varies from 12 per cent. to 26 per cent. of metallic manganese. Some of the bright, rose-red specimens contain sufficient manganese to be classed as rhodochrosite. Most of the carbonate is ferriferous rather than calciferous, although both varieties have been found in many localities.

Origin of the Veins.—The composition of the veins gives no indication as to their origin, but their structure and texture indicates that the deposition took place later than the period of major deformation in that region. Numerous intrusives have been identified on the Cuyuna Range.[7] Many of them are intensely metamorphosed but others show slight, if any, metamorphism. In some cases unaltered dikes cut the igneous schists that are interbedded with the Deerwood formation. Similar relations are found on the Marquette and Menominee ranges in Michigan. There the metamorphosed intrusives and interbedded extrusive are mapped as Upper Huronian.[8] Undoubtedly many of the gray schists of the Cuyuna Range represent igneous action of a similar nature. The manganiferous carbonate veins, however, are associated with a later period of igneous intrusion and may represent emanations from the Keweenawan intrusives of that region.

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[7] Harder, E. C., and Johnston, A. W., *op. cit.*

[8] Van Hise and Leith, Mono. 52, U. S. Geol. Survey.

EDITORIAL

A SEDIMENTARY PROBLEM.

ALL but an insignificant fraction of the world's iron ore comes from sedimentary iron formations, including, among others, the pre-Cambrian iron formations of the Lake Superior region, the Clinton ores of the southern Appalachians, the Wabana ores of Newfoundland, and the minette and oölitic ores of Lorraine and England. Large undeveloped reserves in Brazil are in the same class. Problems of distribution, structure, and secondary concentration of the iron ores in these formations have been pretty well solved, but the question of the ultimate source of the iron and the sedimentary processes which segregated them on such an immense scale is yet in the main unanswered.

Formations of this class extend over thousands of square miles, and some of them range in thickness to a thousand feet or more. All are well bedded. The originally deposited materials are iron oxide, iron carbonate, iron silicates, more or less interbedded with chert or sand or other sediments. In the main they are clearly chemical sediments, to a slight extent organic, and locally a small amount of fragmental deposition may be noted. They all lie within conformable successions of beds, between layers of sandstone, shale, or limestone, and not directly on an old erosion surface or surface of unconformity. The order of deposition of these conformable sedimentary successions shows no uniformity. The iron formation in one case may be preceded by a shale and followed by a limestone, and the order is reversed in another. All seem to be marine sediments deposited in waters of shallow to moderate depth. The range of depth, however, seems to be about as great as for ordinary sediments with which the iron formations are associated.

No common feature has yet been ascertained in the composi-

tion, topography, or conditions of weathering of the old surfaces which yielded the sediments of which the iron formations are a part. Iron formations have resulted whether the adjacent land area was dominantly granitic, basaltic, or sedimentary, or whether erosion reached base level or not.

The extremely wide variations in latitude among the different iron formations suggest that their deposition was not controlled closely by climate.

An examination of present day conditions of erosion and deposition fails to throw much light on the problem. In various parts of the world bog, lake, stream, and shore deposits of ferruginous sediments are being formed, but in no case is the sedimentation of a scale and type to indicate that this was the process which produced the great iron formations of the geologic column. Most of these modern deposits are only a few feet thick, and are extremely localized in area. Furthermore, they do not commonly have the regular banding and interlayering of foreign material so characteristic of the older formations. They fall a long way short of explaining well bedded formations many hundreds of feet thick extending over tens of thousands of square miles.

When we examine the manner of weathering of present land surfaces to see how the iron is behaving, we are confronted with the amply proved fact that iron is being removed in solution to a less extent than any other element with the exception of aluminum. Most of it remains as oxide with the weathering products. Among these are the lateritic iron deposits. The amount which goes out in solution is so minute that it is difficult to believe that this can be the source of the abundant iron solutions necessary to make a great sedimentary iron formation. Much of the Lake Superior iron formation was in the highly soluble form of iron carbonate and iron silicate when first exposed to the erosion surface, yet almost none of it was taken away in solution. It was oxidized and remained in place, while the interlayered quartz bands, usually supposed to be highly insoluble, were taken away, thus enriching the formation into ore bodies. It is true that locally in regions of heavy vegetation the organic acids are ex-

tracting larger portions of the iron, but in the most favorable conditions yet observed the scale does not seem to be such as to offer a reasonable explanation for the large iron formations of the past. Even when iron is notably taken out, much of it is deposited locally as bog ore, or brown ore, or lake ore; the transport soon breaks down.

The fact that iron formations are not normal results of the common cycle of erosion and deposition exhibited in the geologic column, but are highly unusual, in itself shows that the process of accumulation must have varied in some essential particular from the process of normal weathering, transportation and deposition which go to make up the common sediments.

What such special conditions are is yet to be ascertained. For part of the Lake Superior iron formations, for the iron formations of Notre Dame Bay, Newfoundland, and for iron formations in many other parts of the world, there is an association with contemporaneous basic volcanics which is supposed to offer a key to the problem of origin. Vulcanism seems to have been the necessary additional factor, in some fashion supplying iron solutions. For the greater part of the sedimentary iron formations of the world, however, including part of the Lake Superior, no such unusual agency as this has been noted, and it seems likely that the cause must lie in some unusual combination of the ordinary factors of weathering, transportation, and deposition,—but what particular combination would accomplish such an extraordinary result is now almost completely unknown. The science of sedimentation has been making great strides in recent years, and it is to be hoped that it will soon furnish us with some sort of clue.

It will be noted that the principal difficulties to be encountered relate to the source of such large amounts of iron salts, and to the transport processes which are able to segregate them so thoroughly, and not to the manner of precipitation from solution after they have been brought together. Simple and well known chemical processes such as oxidation adequately account for precipitation on a large scale; also organic agencies such as bacteria

and algæ are known to take part in this phase of the work. The evidence as yet available indicates that organic agencies are subordinate to chemical agencies, and perhaps merely take advantage of favorable physical and chemical environments. The problem is to know what constituted this environment, rather than what precipitated the iron salts after the environment was made. When here or there small traces of organisms such as algæ or bacteria are found, it does not do merely to ascribe the origin of formation to the action of organic agencies. This begs the main question. The suggestion has been made that iron bacteria may have had something to do with precipitation of the Brazilian iron ores, but this hardly touches the main problem of sources and segregation. Similarly in the Lake Superior region there is local evidence found in a small fraction of the iron formations that algæ had something to do with deposition, although for much of the larger parts of the formation this evidence is lacking. Again this gives no answer to the main problem relating to the source of the solutions. The evidence of organic agencies relates to a part of the process which has been the least difficult to understand.

It seems likely that enough facts are already known to tell the story. What is needed is careful correlation and interpretation of these facts to give us a real picture of the broad environmental conditions necessary to produce this unusual phase of sedimentation. Except in special cases where there is contemporaneous vulcanism, I believe that this picture will indicate processes now operating and now known, but combined in some specific and unusual way.

C. K. Leith.

DISCUSSION AND INFORMAL COMMUNICATIONS

ARIZONA ASBESTOS DEPOSITS.

Sir: I wish to submit a few notes regarding the paper on "An Arizona Asbestos Deposit," [1] by A. M. Bateman, and the discussion which accompanies it.

A strong case has been presented for the origin of the asbestos veins in the Arizona field by replacement of serpentine of the walls. A completely satisfactory explanation, however, must account for other features which seem to me to be at variance with this theory.

First, is the occurrence of many minerals, other than chrysotile, in cross fiber veins; for example, crocidolite, amosite (ferro-anthophyllite), and such extremes as magnetite,[2] gypsum,[3] and pickeringite.[4] In the Arizona field veins of fibrous calcite are commonly associated with the chrysotile veins, and the fibers in the calcite veins are parallel to those of the chrysotile. In fact, in all veins within a fiber-bearing band the orientation of the fibers is the same, regardless of the position and trend of the opening in which they occur, and therefore it is common to find fibers not oriented perpendicular to the walls. Fig. 45 illustrates an instance where the calcite is clearly later than chrysotile and not formed by replacement. The calcite-forming solution has come in later along the walls of the chrysotile vein, and the specimen

[1] This Journal, vol. XVIII, pp. 663–680, 1923.

[2] Reid, A. McIntosh, "Asbestos in the Beaconsfield District, Tasmania," Geological Survey Rept. No. 8, p. 9 and Plate 7, 1919.

[3] See especially Taber, Stephen, "The Origin of Veinlets in the Silurian and Devonian Strata of Central New York," *Jour. Geol.*, vol. 26, pp. 56–73, 1918.

[4] A very fine specimen from Equador, examined by the writer, occurs with sulphur and selenite. Immediate wall of vein unknown.

illustrated shows the calcite vein cutting from one wall to the other. The structure is similar in both veins, due probably to the same cause—crystals growing under limiting pressure—and

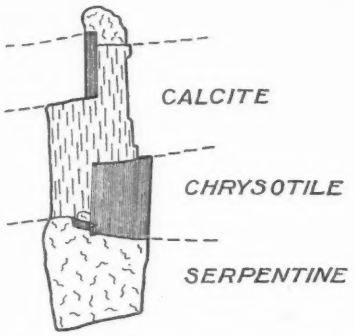

FIG. 45. Calcite vein cutting and running parallel to chrysotile vein, both showing cross-fiber structure. Illustrates that minerals did not form by replacement of walls. Mine of American Ores and Asbestos Co., near Pocket Creek, Sierra Ancha, Gila County, Arizona.

it seems reasonable to conclude that both veins have grown by displacement of the walls rather than by replacement. At the present state of our knowledge it would appear that fibrous chrysotile can be formed by two processes, replacement and displacement. I favor displacement as the more important process.

The question of harshness of fiber is raised in the discussion wihch follows Mr. Bateman's paper. It seems to me that the effect of cleavage has not been sufficiently considered. If a broken end of soft fiber be viewed under the microscope there appears to be no limit to the degree of sub-division that may be obtained. Is this not analogous to micaceous cleavage? All gradations may be observed between indistinctly crystalline serpentine and soft fiber chrysotile. In the chrysotile the fibers are probably in strictly parallel growth. The fact that it can be reduced to extremely fine, loose fibers is probably due to cleavage rather than to the splitting apart of original faces in individual crystals.

Another point that might be made concerning some of the Arizona deposits other than the one which Mr. Bateman describes is the relation of these deposits to structural features, this point having particular significance in the finding of new deposits. The deposits occur at a very definite horizon, as Mr. Bateman pointed out, in the Mescal limestone, which lies horizontally and is split by sills of diabase. The structure of the region as a whole is simple, but in places there are intrusions which cut across the strata, and in some places there is a local bowing or breaking of the sediments. It is at such irregularities that the deposits are generally formed, and that fact may be and is used advantageously in prospecting.

An interesting feature in the Arizona field to the east of the area that Mr. Bateman studied is the fact that the Mescal limestone has at its top a very massive cryptozoan reef about fifty feet thick. It appears that the deposits in this part of the field are almost without exception directly under this impervious capping. Such is the mode of occurrence at the Johns-Manville mine, the largest in the district. In that mine much asbestos has been found right under the reef, but none in the reef. An impervious capping, then, seems to be very favorable to the formation of deposits, and where there is any doming or irregularity of the surface, there again deposits will most likely be found.

I may add that the kind of deposit which Mr. Bateman describes, the limestone type, is not restricted to Arizona. It is known in South Africa, especially the Carolina district.[5] It is also known in Montana, near the Yellowstone Park,[6] and also, judging from specimens, in Japan and Manchuria.

[5] Hall, A. L., "Asbestos in the Union of South Africa," Union S. Africa Geol. Survey, Mem. 12, 1918.

[6] Mineral Resources, U. S., 1920, p. 318.

EDWARD SAMPSON.

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THE PERMEABILITY OF ROCKS.

Sir: Mining has reached the depth of 6000 feet in four districts—Michigan, South Africa, South India, and Brazil. In many mines work is going on at depths of 2000 to 5000 feet. It should thus be possible to obtain accurate statements from all parts of the world concerning the permeability of rocks for liquids and gases, and the change of humidity with increasing depth, which would help in determining conditions at greater depths. In regions where contact- or dynamo-metamorphism has probably not occurred, we could find the possibility for metamorphism and for metasomatism in the formation of rocks and ores.

In order to arouse interest in collecting such data, the following short description is given of the conditions underground observed by the writer as inspector of mines during 35 years in Sweden and in several other countries.

When a sediment is laid down in water, the water is pressed upward, as when sand is dropped in a vessel filled with water. The percentage of water in the deposit decreases with the depth. It is often found in mines that a fissure which contains considerable water in shallow depths is dry 500 or 800 feet further down. In hard rocks, fissures can carry water to much greater depths than in soft rocks. In the very hard rocks and ores in Sweden water still drips at the depth of 1800 feet, but the amount of water is so scanty that presumably no water will appear 500 feet deeper. Sandstone may in this case be considered as soft rock, as English inspectors of mines have asserted that sandstone is generally dry before the workings have proceeded to the depth of 500 feet.

In the last century the mines at Przibram, Bohemia, were the deepest mines in the world, and a depth of 1000 meters was reached in the year 1875 even with the technical resources of that time, as no pump was required below the 650-meter level. No water appeared deeper down, and the water from higher levels was held back. In those days the dry rock at Przibram was regarded as a peculiarity. A great many coal mines were

then worked in dry rock but the dryness was not noticed, as considerable water came from above. The same conditions were found in other mines.

The rock and ore in the copper mines in Michigan are extremely dry at great depths. The amount of humidity can be calculated approximately with the aid of statements given by A. C. Lane in "Keweenawan Series of Michigan."

Small quantities of liquids have been found in rocks otherwise dry, and when analyzed they were found to be solutions composed mostly of NaCl and $CaCl_2$. Those found on higher levels contained more NaCl than $CaCl_2$, but the percentage of $CaCl_2$ and the concentration of the solutions increased with the depth, so that their osmotic pressures increased almost with the rock pressure. The solutions found at the greatest depths were almost saturated at the boiling temperature 104.5° C., containing $CaCl_2$ and NaCl in proportions of 3 to 1. By leaching the dry rock or ore at these depths a solution of these salts results in the above proportions, so that it seems as if a mineral occurred with the composition $3CaCl_2NaCl$. When the dry ore is brought up, it absorbs so much water from the damp air that it looks wet and sticky.

If water existed in the pores of the rock the salt would have absorbed water and been dissolved. The same would have happened if the pores had contained water vapor of greater pressure than the vapor pressure above the saturated solution of the salt. From the boiling temperature of the almost saturated solution we can conclude that its vapor pressure cannot be higher than 5/6 of the vapor pressure above pure water. The pressure of saturated water vapor is 31.5 mm. Hg at 30°, and the vapor pressure of the salt cannot be higher than 26.5 mm. Hg., at which pressure its weight is 27 grams per cubic meter.

L. H. Adams and E. D. Williamson state [1] that porosity varies between 0.8 per cent. to 0.05 per cent. at atmospheric pressure. We estimate the porosity of the rock in question to be 0.4 per cent. in situ, and assume that the pores contain nothing but water

[1] "The Compressibility of Minerals and Rocks at High Pressures," by L. H. Adams and E. D. Williamson, Geophys. Lab. No. 484.

vapor. This gives, per cubic meter of rock, $0.004 \times 27 = 0.1$ gram H_2O; the humidity is only one twenty-seven millionth part of the rock.

To show how little the calculated amount of humidity really is, the amount of water is calculated which is consumed in the formation of mica, containing 4 per cent. of water. If the rock is composed of 3 per cent. mica, we find that one cubic meter of rock, weighing 2700 kg., contains 81 kg. of mica, which contains 3.24 kg. of water. The formation of 1 cubic meter of rock would consume the total amount of humidity in 31,400 cubic meters of rock containing only 0.1 gram per cubic meter; but let us suppose that the rock in the copper fields of Michigan is abnormally dry.

Concerning his experience in deep drilling M. R. Campbell says:[2]

> When the anticlinal theory was first propounded it seems to have been taken for granted that all rocks composing the outer crust of the earth are saturated with water, but recently deep drilling has shown that whereas such is generally the condition of rocks for a few hundred feet below the surface, at great depths the rocks are generally dry, or at least in certain localities they are so dry that water must be pumped into the hole in order that the drilling may proceed.

Rock at great depths seems to be semi-permeable—permeable for gases but not for liquids. The temperature and the corresponding pressure of saturated steam decreases upwards, and the difference in the pressure might during geological time have caused the water to distill upwards to cooler territory, from which the water could have migrated further upwards, mostly through fissures.

Below the crust of rocks is presumably magma containing considerable water, but at the temperature of the magma the attraction between H_2O molecules and SiO_2 molecules, for example, might be so strong that equilibrium would exist with steam pressure decreased but still fairly high. The water vapor might pass through the rocks and be condensed, so that the rocks would be saturated, but if it is stated that they are not, we must consider

[2] "Petroleum and Natural Gas Resources of Canada," 1914, p. 79.

that in the vicinity of the magma the rock is sealed or glazed by partially dissolved minerals so that this part of the crust is gas-tight.

Since the opinions of geologists are so divergent on this subject, it would be of scientific value to collect data from a great many mines. Accurate information is particularly wanted concerning the greatest vertical depth at which continuous dripping —not caused by caving—has been observed, and also concerning the main rock of the mine. The ground below that where water appears may be defined as the dry ground; we will suppose that in this part of the rock crust the pores of the rocks either do not contain water or are only partially filled with water. Statements are desirable concerning the percentage or amount of water as humidity, but care should be taken in the sampling. It was stated above that water is consumed in deep holes, or that the walls of the hole absorb water, as would be the case for the walls of a mine at great depths. The heavy rock pressure is relieved at the surface of the wall, the rock expands and seems to suck water, which can be condensed and taken into its pores by capillarity. Thus the sample for determining the humidity of the rock ought to be taken from a level soon after blasting, and kept in a fairly air-tight vessel. If, after leaching with water, the rock is found to contain easily soluble salts, it may be advisable not to pulverize the sample, but to clean the pieces of rock from dust with a brush and weight a number of thin slivers. Even when the loss of weight after the sample is dried is very slight, a maximum loss in grams per ton should be mentioned.

TH. DAHLBLOM.

FALUN, SWEDEN.

THE COPPER ORES AND DIABASES OF TRANSYLVANIA.

Sir: In the geologic structure of Transylvania different varieties of Triassic eruptive rocks play an important part, including predominating porphyrites and several kinds of diabases. With them occurs some genuine melaphyre.

Besides the enormous masses of diabase (about 700 square km.) of the Dròcsa Mountain range, adjacent to the Transylvanian Erzgebirge are extensive areas in the Koeroesbanyaer group north from Zam through Almàsszelistye-Almasel-Kazanesd to Alvaca, in the Toroćkoer chain near Csegez, in the Persanyer Mountains in the neighborhood of Alsorakos and Lupsa and finally in the eastern part of Transylvania in the Csikgyergyoer Mountain in the Nagyhagymaser chain.

In all these places spilitic augite diabases are dominant, passing downward into granular ophitic diabases and still deeper into coarser-grained gabbrodiabases; at the bottom of very deep valleys the transition goes to gabbro. These copper ores associated with diabase have been mined a little in many places, but an active, permanent, and successful mining industry has been developed in only a few places.

The greatest mine is at Bàlànbanya in the Csikgyergyoer Mountains where the copper ores occur under the following conditions: The important diabase massif of the Nagyhagymàs divides to the west near the Olt River and beyond into individual dikes which might be said to be really interwoven with the crystalline schists (metamorphosed Paleozoic sediments) and the superincumbent highly altered diabase tuffs—diabase schists and chlorite schists of previous authors.[1] These diabase schists occur in a long narrow belt, about a half kilometer wide, and appear to be somewhat earlier than the diabase dikes.

The formation of the Nagyhagymàs diabase belt began with explosive tuffs, whereas the dike material is derived from the remainder of the magma after the rising up of the principal mass of diabase; this also explains their greater content of sulphide ores. The rock of the dikes is a granular uralite diabase with much epidote. The diabase schists also contain considerable epidote. Naturally these old Triassic lodes are not in their orig-

[1] Herbich, *Jahrbuch d. k. ungarischen geologischen Anstalt.*, vol. V., pp. 69–71, Budapest, 1878. Weiss, Taddeus, *idem*, vol. IX., pp. 158–159, Budapest, 1891. Goebl, "Gesterreich Zeitschrift fur Berg und Huettenwesen," vol. XXXIII., ver. mitt., pp. 38–39, Vienna. Stelzner, Bergeat, "Die Erzlagerstaetten," vol. I., 1904, p. 288.

inal condition. The country rock, the original diabase tuff, has been crushed principally at the time of the great Carpathian folding, so that it has in most places the character of a phyllite, or of a crystalline schist. Great faults and overthrusts have also disturbed the original position and bedding. Here and there the diabase schists are braided into the Paleozoic sediments, now mostly converted into mica-schists.

Most of the sulphide ores are not in the diabase dikes, but in the invaded diabase schists near the dikes or occasionally farther away. In the diabase the ores are mainly disseminated, while in the invaded rocks they occur in association with quartz and are of the lens-in-schist type. Mining, carried on for over 100 years, has proved four principal veins which are in general conformable to the present schistosity of the diabase schists.

The geological relations of the region indicate that there is in depth a large gabbroid mass the uppermost apophyses of which are occasionally seen in the diabase dikes which have risen to a certain height, and in the spilitic sheets which have overflowed on the surface. The ore-bearing solutions freed in the crystallization of this gabbro mass saturated not only the joints and fissures in the eruptives and contact rocks, but also the whole mass of the rock over a wide area and produced ore impregnation. The solutions with their ore and silica content penetrated into the beds of former sediments, but even more easily into the diabase tuffs which had suffered only partial diagenesis, and produced there the bedded lodes which are, however, genetically connected with the principal lodes.

The original sulphides have undergone enrichment at certain levels. This enrichment zone is only partly worked out at the mines of Bàlànbanya. In a somewhat higher level oxides were formed from the decomposed sulphides, and native copper and sulphates as well. At the very top are carbonates and hydroxides. The oxidation zone is unimportant in Bàlànbanya. Native copper occurs principally in the oxidation zone, but occurs also in minute quantities in deeper zones. The formation of cement copper may also be well observed in the mine drifts. Here the mine

water becomes charged with sulphates from the decomposing sulphides and from it the copper is precipitated either with the help of the simultaneously formed ferrous compounds or by the pyritic ores themselves. There is no doubt that native copper is formed in the same way both in the zone of cementation and the zone of oxidation, that is to say, in the Bàlànbanya mines it is a supergene mineral.

Near the lodes the spilitic diabases are cut by porphyrites, but only in the west part of the mine. These are also cupriferous, but the ore bodies are all in the diabase. Six principal ore bodies are known in which compact pyrite and chalcopyrite are intimately intergrown. This is also true of the thin veins which connect the ore bodies and of the scattered large nests of ore that occur in the thoroughly decomposed diabase. These ores also occur disseminated in large amounts.

Concomitant minerals are: bornite, chalcocite, and a very minute quantity of native copper. The ore bodies, nests or pockets or ore and thin veins of ore always come with quartz, rarely also with calcite and epidote.

From the geological conditions the writer came to the conclusion that the sulphide ores were formed both under the influence of the post-volcanic activity of the diabase and also under that of the immediately subsequent porphyrite eruption, in the same way as at Bàlànbanya. The ore bodies show no sharp boundaries against the diabase country rock, since this also is charged with sulphides, not only near the ore bodies, but throughout. The thin veins and the pockets of ore are much more sharply limited. The mining of Csegez is very primitive; work is done principally in winter when there is no farm work.

In the Koeroesbànyaer group of the Erzgebirge (Ore Mountains) mining is carried on on a large scale. The most important mines for the copper ores are in the vicinity of Almasel. The dominant rock is here the Triassic diabase, cut by Cretaceous granodiorites, granitites, and the dike rocks belonging to them. Near the village there are five copper mines, worked by open-cut methods, in which the strike of the ore bodies is the same as the Upper Cretaceous dikes and veins.

North from the Balan mine occur only thin lodes, generally parallel, but near Kazanesd a considerable system of lodes is once more exposed, like that of Balan. It is interesting that while in the drifts and adits themselves the highest horizons carry mainly carbonates, close to the surface and on the mountain ridge considerable pockets of limonite and the "iron hat" also characterize the copper lodes.

East of Almasel in the neighborhood of Almasszelistye copper ores occur in philitic and ophitic uralite diabases. The ores are in the mine of Goroni (principal lode, width 50 cm. with 6.25 per cent. copper, associated with quartz and argentiferous pyrite). There is a good prospect for the future indicated also at the mine "Barbara" in the neighborhood of Mikanesd, where the copper content of some lodes reaches 3.45 per cent.

North from here in the neighborhood of Kazanesd along the Tatar and Ponor brooks, copper ore bodies also occur in diabase, but in most places it can be shown that a part of the ores are genetically associated with dikes of Cretaceous granodiorite. This is the case in the "old copper mine" (Alten Kupferbergbau) where besides the principal lode one meter thick, a whole series of thinner lodes occur. The vein material is mainly chalcopyrite, pyrite, and quartz, and chrysocolla has been found here, besides the secondary minerals already mentioned. The richest of the pipe or stock-like lodes at the mouth of the Tatar occurs next to a dike of granodiorite porphyrite. It contains quartz, chalcopyrite, and bornite, with pyrite and marcasite, and the copper content rises to as much as fifteen per cent. in copper veinlets only a few centimeters thick. The average content of the latter is four per cent.

Similar copper mines in this district are the Roxuca, Miklos, and Industriebahn. In all these places the origin of the sulphide ores may be referred to pneumatohydatogenic and thermal action.

West of the Alvaca in the mines of Csungan (Cserboja, Entre Gardur, Prislop Boi) chalcopyrite, generally with pyrite and their respective alteration products, plays a relatively unim-

portant part. However, there is a fairly active mining industry here, for sporadic lodes with rich ore occur. For instance, at the entrance to the Cserboja masses of sulphides occur which contain 6.8 per cent. copper, and in the lodes of the Boi mine the copper content is three per cent.[2]

In the Erzgebirge there are, besides the copper ores that almost always accompany gold ore deposits, many copper deposits, either inadequately or not at all developed (*e.g.,*) near Nyavalyàsfalva, where native copper also occurs, and in the region of Kristor, Pojana, and Cerhia, etc. These deposits are due in part to the effect of the post-volcanic activity of the Triassic diabases and augite porphyrites (melaphyres of previous authors), and also are due to the more recent eruptives, which cut the diabases and augite porphyrites. Their type in general, however, is that of the occurrences described above. But besides these there are copper deposits which are throughout their whole extent connected with the Upper Cretaceous granitites and granodiorites, *e.g.,* the famous old copper mines of Rezbanya in the Bihar mountains.

In general, it may be said that the copper mining of Transylvania is still in a very primitive condition, although the prospects for mining in a modest way are certainly hopeful.

[2] Papp, Jahresbericht (annual report) d. kgl. ungarischen geologischen Reichsanstalt f.d.j. 1903, p. 87, Budapest, 1905.

The full original paper gives numerous references to official reports by Papp, Lachner, Herbich, Weiss, Goebl.

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REVIEWS

Structural Geology (Revised Edition). By C. K. LEITH. Henry Holt and Company, New York, 1923. 390 pages, 103 text figures.

Students and teachers of structural geology will welcome this new edition of Leith's standard text, which retains many excellent features and omits certain discrepancies present in the edition of 1913. New material has been added, more than doubling the number of pages; discussion of many subjects has been entirely recast, to make for clearness and to take account of new developments in the science; and the general approach to the whole subject has been changed with the idea of leading from facts of observation to considerations involving speculation. Without question the result has been to make a better balanced and more comprehensive text. Strong emphasis is still given to structural features characteristic of the Lake Superior region, but the reader is more than glad to have the benefit of Leith's rich experience in pre-Cambrian geology. The new book is not only highly instructive but is very attractive in appearance and more readable than the average text devoted to subjects equally technical.

Differences of opinion regarding matters of usage or interpretation are inevitable, and no doubt each reader of Leith's book will voice certain objections. Thus petrologists who think the term *porphyritic* should be restricted to textures of igneous origin will criticise its repeated use by Leith to designate that structure in metamorphic rocks for which the term *porphyroblastic* has been proposed. Moreover some students of rock shearing will not consider Leith's treatment of this subject adequate. Indeed, although his discussion on this point is more satisfactory than in the old book, it does not seem entirely consistent. A photograph of crushed wooden blocks (p. 34) is supposed to illustrate the "tendency of fractures to follow shearing planes 45° to the pressure"; yet the angles, as actually measured with a protractor, are about 60°. Again, he states that "the strain ellipsoid has two planes of no distortion nearly at right angles to each other"; but his own models and field illustrations show that the angle may differ widely from 90°. Elsewhere he concludes that the angle of shear may vary considerably, on both sides of 45°, according to the nature of the substance and the degree of load-

ing. He points out, very properly, the prevalence of rotational strains in nature and the consequent difficulties in analyzing joints. It does not appear, however, that some of the views recently set forth by Bucher can be entirely disregarded as working hypotheses.

In defining the elements of faults the author states that his definitions "follow on the whole those proposed by a committee of the Geological Society of America in 1912." Yet he has departed radically from the usage of the committee with regard to the components of displacement, as referred to rectangular coördinates. *Heave* he defines as "the horizontal component of the slip or shift." The reader at once wonders which component is meant, since there are commonly two in the horizontal plane, mutually at right angles. It develops that Leith refers to the component parallel to the strike of the fault. Introduction of this usage into a standard text is to be deplored; for while it is true that fault nomenclature is highly varied, perhaps no term has been regarded as more nearly standardized than *heave*, used with reference to the horizontal component at right angles to the strike of the fault. Moreover, Leith offers no substitute term for this component. *Offset* is defined as "the horizontal distance between the two parts of a dislocated bed at right angles to the strike of the strata"; but the attitude of strata has no necessary relation to the attitude of a fault. Leith's definitions, therefore, involve more than a mere difference in terms. For some cases of dip faults *heave* and *offset*, as he uses the terms, would be identical, and there would be no word to designate the other horizontal component.

C. R. LONGWELL.

Petrology for Students (6th ed.). By Alfred Harker. Pp. 302 with 100 figures. Cambridge Geological Series, Cambridge University Press. England, 1923.

The latest edition of this standard textbook differs only slightly from the preceding one. The few changes in subject matter consist mainly of examples from additional localities. Four new figures have been substituted, and all are printed lighter and more clearly.

Readers unacquainted with the earlier editions will discover here a well-written, concise treatment of the descriptive study of rocks especially in thin sections. Although the majority of examples are drawn from Great Britain, the book is scarcely less valuable to American students on that account.

JOHN B. STONE.

Rocks and their Origins. By G. A. J. COLE. Pp. 175, with 20 figures. Cambridge Manuals of Science and Literature, Cambridge University Press. 1922.

This entertaining little book is intended for those who are not specialists in geology. Perhaps it may have difficulty in realizing its objective because of the frequent use of scientific terms without explanation, but for the reader with even a slight knowledge of geology it is unusually readable and instructive. The treatment is broad, dealing chiefly with the origins of rocks and their influence on scenery and not with the study of hand specimens. Unfortunately the illustrations are not distinct, but this is not a serious defect since the text is sufficiently clear without them.

JOHN B. STONE.

SOCIETY OF ECONOMIC GEOLOGISTS

The Society of Economic Geologists held its annual technical meeting, through the courtesy of the President of Columbia University, Dr. Nicholas Murray Butler, at Schermerhorn Hall, Columbia University, New York, May 23, 1924. Two technical sessions were held, attended by 28 members and some 25 guests, a total of 52. The program follows:

Morning Session, Professor Charles P. Berkey, Presiding.

1. Types of Magnesite Deposits and Their Origin—George W. Bain (introduced by J. F. Kemp).
2. Alabama Graphite Deposits—John S. Brown (introduced by J. F. Kemp).
3. Angular Inclusions and Replacement Deposits—Alan M. Bateman.
4. Magnetite Deposits of Southeastern New York—R. J. Colony (introduced by J. F. Kemp).
5. A Comparison of Recoverable and Recovered Zinc—C. E. Siebenthal.
6. Salt, Anhydrite, and Gypsum of the Salina Formation—D. H. Newland.
7. A Review of the Ore Deposits of Grass Valley, California—Ernest Howe.

Afternoon Session, Mr. George H. Ashley, Presiding.

Presidential Address—Pegmatites—Professor James F. Kemp.

8. Molybdenite Deposit near New Ross, Nova Scotia—Charles W. Cook.
9. The Camp Bird Vein, Ouray, Colorado—J. E. Spurr.
10. The Occurrence of Vanadium and Nickel in Petroleum—E. DeGolyer.
11. Economic Aspects of the Geology of the Slate Deposits of Eastern Pennsylvania—Charles H. Behre, Jr. (introduced by G. H. Ashley).
12. Base Exchange in Ground Water in Montana—B. Coleman Renick (introduced by D. F. Hewett).
13. The Relative Age of the Mine Hill Zinc Ore Body, Franklin Furnace, N. J.—Frank L. Nason.

The following papers were read by title:

1. Geology of the Beatson Copper Mine, Alaska—Alan M. Bateman.
2. Injection Versus Replacement in the Pre-Cambrian Iron Ores of Missouri—John S. Brown (introduced by J. F. Kemp).

3. Some Facts about Washington Geology and Its Oil and Gas Prospects—Dorsey Hager.
4. A Magmatic Sulphide Ore from the Chicagof Island, Alaska—Paul S. Kerr (introduced by J. F. Kemp).
5. Continuity of Some Oil-Bearing Sands of Wyoming and Montana—Willis T. Lee.
6. The Pyrophyllite Deposits of the Deep River Region of North Carolina—J. L. Stuckey (introduced by Heinrich Reis).
7. Chemistry of the Formation of the Oxidized Zinc Ores—Thomas L. Watson.
8. Chart on Coal Classification—George H. Ashley.
9. Geology and Oil Possibilities of the Arctic Coast—Sidney Paige.
10. The Caridad Mine, Sonora, Mexico—Alfred Wandke.
11. Molecular Migration and Mineral Transformation—Alfred Wandke.
12. Shattering by Replacement—Alfred Wandke.

On Friday evening, May 23, a dinner was held at the Harvard Club, New York, which was attended by some twenty-seven members.

Past President Spurr was toastmaster and President Kemp and others spoke. Professor Lindgren brought up the difficulty of finding employment for graduate geologists due to the depressed condition of the mining industry, and this led to an extended discussion as to the future of economic geology and the subject of education therein.

On Saturday, May 24th, seventeen members attended an excursion to Franklin Furnace, N. J., where the surface geology was examined in detail.

KANSAS STATE AGRICULTURAL COLLEGE
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SCIENTIFIC NOTES AND NEWS

George Otis Smith, Director of the U. S. Geological Survey, has been in California, where the President's Commission on Oil Reserves has been investigating the California oil reserves. They returned by way of Wyoming to look into the question of Teapot Dome.

Ralph Arnold, of Los Angeles, was injured in an automobile accident in April, suffering a fracture of the hip bone.

David White has been elected chairman of the Division of Geology and Geography of the National Research Council.

C. K. Leith, of Madison, Wisconsin, is studying subsidence at the Newport mine on the Gogebic Range, assisted by Stephen J. Royce, of Crystal Falls, Michigan.

Kenneth C. Heald, formerly of the gas and oil section of the U. S. Geological Survey, has been appointed associate professor of geology at Yale and will work, particularly, in the field of sedimentation.

E. L. Bruce, of Queen's University, Kingston, Ontario, will be engaged this summer in making geological surveys in the region west of Port Arthur.

J. D. Sears of the U. S. Geological Survey has been in Colorado to discover whether the geologic conditions in the northeastern part of the State are favorable to the occurrence of oil.

F. A. Bather has been appointed Keeper of Geology at the British Museum, to succeed D. A. Smith Woodward, who has retired.

Edward Sampson, of the U. S. Geological Survey, is in Globe, Arizona, working in the Arizona asbestos fields until July 1. The geologic mapping will be based on airplane photographs made by the Air Service of the War Department.

R. C. Wallace, professor of geology in the University of Manitoba, and president of the Canadian Institute of Mining and Metallurgy, is in England on official business for the Manitoba Government.

F. H. Moffit, of the U. S. Geological Survey, is making geologic surveys in the Prince William Sound region, Alaska.

J. W. Evans, lecturer in petrology at the Imperial College of Science and Technology, London, was recently elected president of the Geological Society of London.

E. S. Moore, of the University of Toronto, will spend the summer studying some of the iron ranges north of Sault Ste. Marie.

Frank Reeves, of the U. S. Geological Survey, is in the Bearpaw Mountains of Montana studying the structure of that region.

L. F. Bullard, of the Treadwell Yukon Gold Company, Ltd., is in the Kuskokwim district, Alaska, where his company has interests in mining properties.

E. K. Soper has recently returned to New York after a year spent in Europe and the Near East in petroleum geology investigations.

W. P. Woodring, of the U. S. Geological Survey, has been in Elk Hills, California, examining Naval Reserve No. 1.

John Stansfield has been appointed assistant professor of geology at the University of Illinois, Urbana.

Percy Hopkins has been examining mining properties in the Lake Fortune and Larder Lake districts for the Victoria Syndicate, Ltd.

E. F. Burchard, of the U. S. Geological Survey, is in the iron-ore district of Alabama, to bring up to date geologic information revealed by drilling and mining developments.

Dean J. Wolff, of Pecos, Texas, formerly geologist for the Gulf Production Company, has accepted a similar position with the Mutual Oil Company of Denver, Colorado.

Ben C. Belt, for over ten years connected with Mexican oil geological work, has left for a professional trip to Australia.

John P. Gray, of Coeur d'Alene, Idaho, gave a series of lectures to students in geology, mining, and law at the University of Wisconsin in April on the subject of the Law of the Apex.

Charles Butts, of the U. S. Geological Survey, has been in Kentucky examining an area in Rowan, Elliott, Menifee, and Morgan counties for the Forest Service. After completing this examination and some field studies in central Kentucky for the State, he will continue his work on the geologic map of Alabama.

C. K. Leith, of the University of Wisconsin, conducted a party of seventeen graduate students, including students from the University of Wisconsin, the University of Chicago, and Northwestern University, on a trip to the Lake Superior iron ranges from May 9 to 18.

C. E. Dobbin is preparing for summer work in the western coal fields for the U. S. Geological Survey.

The British Association for the Advancement of Science will hold its 92d annual meeting in Toronto, Canada, August 6 to 13. Section C relates to geology, of which the chairman is W. W. Watts, professor of geology in the Imperial College of Science and Technology of London, and the secretary is E. S. Moore, of the department of geology of the University of Toronto. A number of papers of general interest in the allied sciences are to be presented, and a mention will be made in the next number of this Journal of the geological papers.